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[TITLE OF THE INVENTION]	ILLUMINATION DEVICE, EXPOSURE APPARATUS PROVIDED WITH THE ILLUMINATION DEVICE, AND METHOD OF FABRICATING SEMICONDUCTOR DEVICE USING THE EXPOSURE APPARATUS
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[Document] Specification

[Title of the Invention] ILLUMINATION DEVICE, EXPOSURE APPARATUS PROVIDED WITH THE ILLUMINATION DEVICE, AND METHOD OF FABRICATING SEMICONDUCTOR DEVICE USING THE EXPOSURE APPARATUS

[Scope of the Claims]

[Claim 1]

An illumination device, comprising:

light source means which provides a light beam, a multi-light source formation optical system which forms many light sources based on the light beam from the light source means, and a condenser optical system which condenses the light beam from the many light sources formed by the multi-light source formation optical system and illuminates an illuminated surface;

the multi-light source formation optical system having a first optical element group including many first optical elements; and

the many first optical elements respectively having a first optical surface having an arc-shaped contour in order to form the many light sources by dividing the light beam from the light source means into many arc-shaped light beams in a manner of wavefront dividing.

[Claim 2]

The illumination device as set forth in claim 1,

wherein optical surfaces of the many first optical elements are respectively formed in a predetermined first reflecting curved surface.

[Claim 3]

The illumination device as set forth in claim 2,

wherein the first optical element is constituted by an eccentric mirror having an optical axis outside an effective region of the first reflecting curved surface.

[Claim 4]

The illumination device as set forth in claim 2 or 3, comprising:

the multi-light source formation optical system further having a second optical element group including many second optical elements;

the many second optical elements respectively having a second optical surface which is formed in a rectangular shape; and

the second optical surface of the many second optical elements being respectively formed in a predetermined second reflecting curved surface.

[Claim 5]

The illumination device as set forth in claim 4, comprising:

the second optical element having an optical axis at a center position of the second optical element.

[Claim 6]

The illumination device as set forth in any one of claims 2-5,

wherein the condenser optical system is constituted only by one or more reflecting type optical elements.

[Claim 7]

The illumination device as set forth in claims 1-6, comprising:

the first optical element group having a plurality of first optical element columns, in which a plurality of the first optical elements are arranged along a predetermined first direction, the columns arranged along a second direction perpendicular to the predetermined first direction, and

the many first optical elements which structure the optical element columns form a light source image which is arranged nonlinearly.

[Claim 8]

The illumination device as set forth in claim 7,

wherein an arbitrary first optical element within the many first optical elements which structure the first optical element column are inclined and arranged with respect to a predetermined plane in which the many first optical elements are arranged so that a direction of the first reflecting curved surface is different.

[Claim 9]

An exposure apparatus, comprising:

an illumination device as set forth in any one of claims 1-8,

a mask stage which can hold a mask arranged at the illuminated surface to be illuminated by the illumination device,

a wafer stage which can hold a photosensitive substrate,

a projection optical system which projects a predetermined pattern formed in the mask onto the photosensitive substrate; and

a driving device which relatively moves the mask stage and the wafer stage with respect to the projection optical system when a predetermined pattern formed in the mask is projected onto the photosensitive substrate.

[Claim 10]

A method of fabricating a semiconductor device, using the exposure apparatus as set forth in claim 9, including:

a step of exposing a pattern of the mask onto the photosensitive substrate via the projection system.

[Detailed Description of the Invention]

[0001]

[Industrial Use of the Invention]

This invention relates to an illumination device which uniformly illuminates an illuminated surface, and more particularly to a desired illumination device and an exposure apparatus used when a semiconductor device is fabricated by a photolithography process. Furthermore, this invention relates to a method of fabricating a desired semiconductor device using the exposure apparatus.

[0002]

[Prior Art]

Conventionally, with respect to an exposure apparatus for fabricating a semiconductor device provided with an illumination device, a circuit pattern formed on a mask is projectingly transferred onto a photosensitive substrate, such as a coated wafer, via projection optical system. This projection optical system has two reflecting mirrors formed of a concave surface mirror and a convex surface mirror. Only a good image portion of an arc-shaped region outside an axis of the projection optical system is used, and only an arc-shaped region on a mask is projectingly transferred onto a wafer. Furthermore, transferring of a circuit pattern of the entire mask can be performed by scanning a mask and a wafer in a predetermined direction.

[0003]

According to this scanning type exposure, there is an advantage that high resolution can be obtained with relatively high throughput.

In this type of exposure apparatus, an illumination device is desired which can uniformly illuminate the entire arc-shaped region on a mask with a predetermined numerical

aperture (NA). For example, Japanese Laid-Open Patent Application 60-232552 discloses an illumination device which can uniformly illuminate a region on a mask in an arc manner.

[0004]

In the illumination device which is disclosed in Japanese Laid-Open Patent Application 60-232552, as shown in Fig. 16(a), a light beam from a super high pressure mercury-arc lamp 21 is condensed onto an incident surface of an optical integrator 23 by an elliptic mirror 22. Furthermore, as shown in Fig. 16(b), this optical integrator 23 is constituted by combining two cylindrical lens assemblies (23a, 23d) having a focal length f_1 and two cylindrical lens assemblies (23b, 23c) having a focal length f_2. A light beam having different numerical apertures in perpendicular directions is formed by this structure. A light beam through the optical integrator 23 is condensed by a condenser lens 24. As shown in Fig. 16(c), a slit plate 25 having an arc-shaped aperture portion 25a is illuminated, and then, a mask which is an illuminated surface is uniformly illuminated via a condensing optical system 26.

[0005]

[Problem to be Solved by the Invention]

However, in the illumination device disclosed in the above-mentioned Japanese Laid-Open Patent Application 60-232552, as shown in Fig. 16(c), a rectangular-shaped region BF is illuminated so as to irradiate the arc-shaped aperture portion 25a on the slit plate, so only a small part of the light beam can be effectively used as arc illumination.

[0006]

In general, an arc-shaped cord length is set to be as long as possible so as to enlarge an exposure region, and an arc-shaped slit width 25b is set to be relatively narrow so as to be restricted to a good image region of a mirror projection optical system which projects a mask onto a wafer. Therefore, illumination effectiveness is determined by an area ratio between the rectangular-shaped region BF and the arc-shaped aperture portion 25a. In a conventional illumination device shown in Figs. 16(a), (b), and (c), there is a fatal disadvantage that a light amount loss is significant in principle. Because of this result, a sufficient light amount cannot be obtained on an irradiating surface (mask or wafer), so scanning speed between a mask and a wafer cannot be accelerated. Therefore, there was a problem that this cannot obtain a high throughput.

[0007]

Accordingly, in this invention, a main object of this invention is to provide an illumination device, solving the above-mentioned problem, in which illumination effectiveness

is much better than a conventional device and can sufficiently obtain a high throughput, and uniform illumination such as Koehler illumination can be accomplished, an exposure apparatus provided with the illumination device, and a method of fabricating a desired semiconductor device using the exposure apparatus.

[0008]

Furthermore, recently, by using a light source device, such as a synchrotron generation device or the like, which provides a soft X ray, an exposure apparatus for the next generation which can project and expose a further micro line width pattern onto a photosensitive substrate is demanded. An illumination device and an exposure apparatus have not been proposed which can uniformly illuminate X ray such as soft X ray or the like onto a mask.

Because of this, in this invention, a secondary object of this invention is to provide an illumination device and an exposure apparatus which can effectively uniformly illuminate X ray onto a mask and a method of fabricating a desired semiconductor device by X ray.

[0009]

[Means of Solving the Problem]

In order to accomplish the above-mentioned main object, in the invention related to claim 1, for example, as shown in Figs. 1 and 8, the light source image formation optical system 2 has a first optical element group (2a, 20a) including many first optical elements (E, E_1), and

the many first optical elements (E, E_1) respectively have first optical surfaces (RS, RS_1) having an arc-shape contour in order to form many light sources by dividing the light beam from a light source means into many arc-shaped light beams in a manner of wavefront dividing.

[0010]

Because of this, the light which has been wavefront-divided into an arc shape by the light source image formation optical system 2 and transmitted to the respective first optical surfaces (RS, RS_1) of the many first optical elements (E, E_1) forms an arc-shaped illumination region and are superimposed on a mask 5 or a wafer 7 or the like as an illuminated surface by a condensing operation (or "action") of a condenser optical system 3. Therefore, uniform illumination can be effectively realized.

[0011]

Furthermore, in the invention related to claim 2, the optical surfaces (RS, RS_1) of the many first optical elements (E, E_1) are respectively formed in a predetermined first reflecting

curved surface. In this case, as described in claim 3, it is preferable that the first optical elements (E, E_1) are constituted by an eccentric mirror having optical axes (Ax_E, Ax_{E1}) outside an effective region of the first reflecting curved surface.

[0012]

Furthermore, in the invention related to claim 4, the multi-light source formation optical system 2 further has a second optical element group 20b including many second optical elements E_2. The many second optical elements E_2 respectively have a rectangular-shaped second optical surface RS_2. The second optical surface RS_2 of the many second optical element E_2 can be respectively formed in a predetermined second reflecting curved surface. By so doing, even if the light having an angle of divergence is provided from a light source means 1, a light beam supplied via the first optical element group 20a is again condensed in the second optical element group 20b effectively, the mask 5, the wafer 7, or the like as an illuminated surface can be effectively illuminated in an arc shape.

[0013]

In this case, like the invention described in claim 5, it is preferable that the second optical element E_2 has an optical axis Ax_{E2} at a center position C_{E2} of the second optical element.

In the invention related to claim 6, the condenser optical system 3 is constituted only by one or more reflecting type optical elements. Because of this, the multi-light source formation optical system 2 and the condenser optical system 3 are constituted only by a reflecting system, so even when an X-ray generation device, such as a synchrotron generation device or the like, which provides X-rays with a wavelength of 20 nm or less is a light source means, a mask 5 or the wafer 7 or the like as an illuminated surface can be uniformly effectively illuminated in an arc shape.

[0014]

In the invention as set forth in claim 7, the first optical element group 20a has a plurality of the first optical element columns, in which many first optical elements E_1 are arranged along a predetermined first direction, the columns being arranged along a second direction perpendicular to the predetermined first direction, and

many first optical elements E_1 which structure the optical element columns are constituted so as to form a light source image arranged nonlinearly. By so doing, for example, a light source image I is formed so as to inscribe the respective second optical elements E_2 of

the second optical element group 20b, so a light amount loss of a light beam going through the respective second optical elements E_2 can be controlled to a minimum.

[0015]

In this case, as set forth in claim 8, it is preferable that an arbitrary first optical element E_1 with many first optical elements E_1 which structure the first optical element column are inclined and arranged with respect to a predetermined plane P_a in which the many first optical elements E_1 are arranged so that the direction of the first reflecting curved surface is different.

Furthermore, in the invention as set forth in claim 9, when the illumination device as set forth in any of claims 1-8, a mask stage MS which holds the mask 5 arranged at the illuminated surface to be illuminated by the illumination device, a substrate stage WS which holds the photosensitive substrate 7, a projection system 6 which projects a predetermined pattern formed in the mask 5 onto the photosensitive substrate, and a predetermined pattern formed in the mask 5 are projected onto the photosensitive substrate 7, driving devices (D_1, D_2) are provided which relatively move the mask stage MS and the substrate stage WS with respect to the projection system 6. By so doing, an exposure apparatus with high throughput can be obtained.

[0016]

In the invention as set forth in claim 10, by using the exposure apparatus as set forth in claim 9, in a method of fabricating a semiconductor device, a step of exposing a pattern of the mask 5 onto the photosensitive substrate 7 via the projection system 6 is included. By so doing, a desired semiconductor device can be fabricated.

[0017]

[Embodiments]

The following explains embodiments of this invention with reference to Figs. 1-4. Fig. 1 is a diagram showing a schematic structure of a first embodiment according to this invention. Fig. 2 is a front view showing a structure of a reflecting element group 2 as a multi-light source formation optical system (optical integrator). Figs. 3(a) and (b) are diagrams showing a structure of the respective reflecting elements E_1 which structure a reflecting type optical element group 2. Fig. 4 is a diagram showing the operation (or "the action") of a reflecting element group 2 as a multi-light source image formation optical system (optical integrator) shown in Fig. 1.

[0018]

As shown in Fig. 1, a laser light beam (parallel light beam) which is provided from a light source means, such as a laser light source or the like, which provides a laser light beam having a wavelength of 200 nm or less is incident substantially perpendicular to the reflecting element group 2, which serves as a multi-light source formation optical system (optical integrator).

Additionally, as a light source means, for example, an ArF excimer laser which provides a laser light beam having a wavelength of 193 nm, an F_2 laser which provides a laser light beam having a wavelength of 157 nm, or the like can be used.

[0019]

Here, the reflecting element group 2 is constituted as many reflecting elements (optical elements) E two-dimensionally arranged in a dense manner along a predetermined first reference plane P_1 perpendicular to a YZ plane. Specifically, as shown in Fig. 2, the reflecting element group 2 has many reflecting elements E having a reflecting curved surface whose contour (outer appearance) is formed in an arc shape. Additionally, this reflecting element group 2 has five columns, arranged along the Y direction, of many reflecting elements, in which many reflecting elements are arranged in a Z direction. Additionally, the five columns of reflecting elements are constituted so as to have a substantially round shape as a whole.

[0020]

Furthermore, a contour shape (arc shape) of each of the reflecting elements E is approximately similar in shape to an arc-shaped illumination region IF formed on a reflecting mask 5 as an illuminated surface which will be described later.

As shown in Figs. 3(a) and (b), the respective reflecting elements have a shape in which part of the reflecting curved surface of a predetermined radius of curvature R_E in a predetermined region which is decentered from the optical axis Ax_E is cut out so that a contour (outer shape) forms an arc shape, and a center C_E of this arc-shaped reflecting element E is located at height h_E from the optical axis Ax_E. Therefore, an eccentric reflecting surface RS_E of the respective reflecting elements E is constituted by an eccentric aspherical mirror having a predetermined radius of curvature R_E as shown in Fig. 3(b). Furthermore, RS_E in Fig. 3(b) shows an effective reflecting region of the reflecting elements E in which a light beam to be incident from the light source means 1 is effectively reflected.

[0021]

Furthermore, as shown in Fig. 3(b), a laser light beam (parallel light beam) L which is incident in a direction parallel to the optical axis Ax_E of the reflecting element E forms a light

source image I which is condensed to a focal point F_E on the optical axis Ax_E of the reflecting element E. Additionally, the focal length f_E of the reflecting element E is a distance between a vertex O_E of the reflecting curved surface of the reflecting element E and the focal point F_E of the reflecting curved surface of the reflecting element E. If a radius of curvature R_E of the reflecting curved surface of the reflecting element E is the distance, the following equation (1) can be established.

(1) $f_E = - R_E / 2$

In Fig. 1, laser light (parallel light beam) which is incident substantially perpendicular to the reflecting element group 2 is divided into arc-shaped light beams in a manner of wavefront dividing by a reflecting operation (or act) of the many reflecting elements E, whereby many light source images corresponding to the number of the many reflecting elements E are formed at a position P_2 shifted from the incident light beam. In other words, if a laser light beam is incident from a direction parallel to the respective optical axes Ax_E of the many reflecting elements E which structure the reflecting element group 2, the light source image I is respectively formed in a plane P_2 passing through the focal point F_E on the respective optical axes Ax_E by a reflecting condensing operation (or action) of the respective reflecting elements E. In the plane P_2 in which many light source images I are formed, many secondary light sources are substantially formed. Therefore, the reflecting element group 2 functions as a light source image formation optical system which forms many light source images I, that is, a multi-light source formation optical system which forms many secondary light sources.

[0022]

The light beam from the many light source images I is incident to a condenser reflecting mirror 3 having an optical axis Ax_C and which serves as a condenser optical system. This condenser reflecting mirror 3 is constituted by one spherical mirror having an effective reflecting surface at a position distant from the optical axis Ax_C, and this spherical mirror has a predetermined radius of curvature R_c. The optical axis Ax_C of the condenser reflecting mirror 3 passes through a center position (position intersecting the plane P_2, in which the light source image R is formed, with the optical axis Ax_C) in which many light source images I are formed by the optical element group 2. However, the focal point of the condenser reflecting mirror 3 exists on this optical axis Ax_C.

[0023]

Furthermore, the optical axis Ax_C of the condenser reflecting mirror 3 is parallel to the respective optical axes Ax_{E1} of the many optical elements E_1 structuring the optical element group 2.

Additionally, after the respective light beams from the many light source images I are respectively reflectingly condensed by the condenser reflecting mirror 3, the reflecting type mask 5 as an illuminated surface is superimposingly illuminated in an arc shape via a flat mirror 4 as a deflecting mirror. Fig. 4 shows an arc-shaped illumination region IF formed on the reflecting type mask 5 when it is seen from a direction shown by arrow A of Fig. 1, that is, from the rear surface of the reflecting type mask 5. A center of curvature O_{IF} of the arc-shaped illumination region IF exists on the optical axis Ax_P of the projection system shown in Fig. 1. Furthermore, in case the flat mirror 4 of Fig. 1 is removed, the illumination region IF is formed at a position of the irradiating surface IP of Fig. 1, and the center of curvature O_{IF} of the illumination region IF exists on the optical axis Ax_C of the condenser optical system 3.

[0024]

Therefore, in the example shown in Fig. 1, the optical axis Ax_C of the condenser optical system 3 is not 90° deflected by the flat mirror 4, but if the optical axis Ax_C of the condenser optical system 3 is 90° deflected by an imaginary reflecting surface 4a of the flat mirror 4 shown in Fig. 1, the optical axis Ax_C of the condenser optical system 3 and the optical axis Ax_P of the projection system 6 are coaxial on the reflecting mask 5. Because of this, it can be said that these optical axes (Ax_c, Ax_P) are optically coaxial. Therefore, the condenser optical system 3 and the projection system 6 are arranged so that the respective optical axes (Ax_c, Ax_P) optically pass through the center of curvature O_{IF} of the arc-shaped illumination region IF.

[0025]

In the surface of the reflecting type mask 5, a predetermined circuit pattern is formed. This reflecting type mask 5 is held by a mask stage MS which is two-dimensionally movable in an XY plane.

Light reflected by this reflecting type mask 5 is imaged onto a wafer W coated by a resist, and thus is a photosensitive substrate, via the projection system 6. Here, an arc-shaped pattern image of the reflecting mask 5 is projectingly transferred. The wafer 7 is held by a substrate stage WS which is two-dimensionally movable in the XY plane.

[0026]

Here, the mask stage MS is two-dimensionally moved along the XY plane via a first driving system D_1, and the substrate stage WS is two-dimensionally moved along the XY plane via a second driving system D_2. The respective driving amounts are controlled by a control system 8 with respect to the two driving systems (D_1, D_2).

Therefore, the control system 8 can move the mask stage MS and the substrate stage WS in a reverse direction (arrow direction) via the two driving systems (D_1, D_2), so the entire pattern formed on the reflecting type mask 5 is scanningly exposed onto the wafer W via the projection system 6. By so doing, a desired circuit pattern, in a photolithography process which fabricates a semiconductor device, is transferred onto the wafer W, so a desired semiconductor device can be fabricated.

[0027]

The projection system 6 having the optical axis Ax_P is constituted by an off-axis type reduction system having four aspherical mirrors (6a-6d) having an effective reflecting surface at a position distant from the optical axis Ax_c. First, third, and fourth aspherical mirrors (6a, 6c, 6d) are constituted by a concave surface type aspherical mirror, and a second aspherical mirror 6b is constituted by a convex surface type aspherical mirror. A pupil of the projection system 6 exists on a reflecting surface of the third aspherical mirror 6c, and an aperture diaphragm or the like is arranged at a position P_S of this pupil.

[0028]

The following explains an operation of the optical element group 2 shown in Fig. 1 with reference to Fig. 5.

Fig. 5 is a diagram showing enlargement of a portion of an illumination device which illuminates the reflecting mask 5 shown in Fig. 1. Fig. 5 omits a flat mirror 4 in order to clarify the explanation. Furthermore, the reflecting element group 2 is constituted by three reflecting elements (E_a-E_c).

[0029]

As explained in Fig. 1, the reflecting element group 2 includes three reflecting elements (E_a-E_c) arranged along a predetermined reference plane P_1, and the predetermined reference plane P_1 is parallel to a plane (YZ plane) passing through a focal point (position of the center of curvature) P_2 of the respective reflecting elements (E_a-E_c).

As shown in Fig. 5, the laser light beam (parallel light beam) which has been incident to the reflecting element E_a within the reflecting element group 2 is divided into arc-shaped

light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the reflecting element E_a, and the wavefront-divided arc-shaped light beams (light beam shown by solid lines) form a light source image I_a by a condensing operation of a reflecting surface of the reflecting element E_a. After that, the light beam from the light source image I_a is condensed by the reflecting surface of the condenser optical system 3, and the reflecting type mask 5 is illuminated in an arc shape from an oblique direction. Furthermore, the paper plane direction of Fig. 5 is a width direction of an arc-shaped illumination region formed on the reflecting type mask 5.

[0030]

Furthermore, the laser light beam (parallel light beam) which is incident to the reflecting element E_C within the reflecting element group 2 is divided into arc-shaped light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the optical element E_C. The wavefront-divided arc-shaped light beams (light beam shown by solid lines) form a light source image I_c by a condensing operation of the reflecting surface of the reflecting element E_c. After that, each light beam from the light source image I_c is condensed by the reflecting surface of the condenser optical system 3, and the reflecting type mask 5 is illuminated in an arc shape by superimposing the light beams on an arc-shaped illumination region shown by solid lines.

[0031]

Thus, the light which went through the respective reflecting element 5 within the reflecting element group 2 is superimposingly illuminated in an arc shape on the reflecting type mask 5, so uniform illumination can be accomplished. Additionally, as shown in Fig. 1, the light source image formed by the respective reflecting elements within the reflecting element group 2 is re-imaged into a position P_s (entrance pupil of the projection system 6) of the pupil of the projection system 6, so that a so-called Koehler illumination can be accomplished.

[0032]

As shown in the above-mentioned first embodiment, in order to expose a pattern of the mask 5 onto the photosensitive substrate 7, even if the illumination device and projection system are entirely constituted by reflecting type members and reflecting type elements, by substantially maintaining the condition of Koehler illumination, an arc-shaped uniform illumination region can be effectively formed on the mask.

Furthermore, by orthogonally projecting a projective relationship of the condenser optical system 3, the reflecting type mask 5 can be illuminated in a uniform numerical aperture NA regardless of the direction.

[0033]

Furthermore, as shown in Fig. 2, many reflecting elements E are densely arranged such that an outer shape (contour) of the reflecting element group 2 is substantially round-shaped, so an outer shape (contour) of a secondary light source formed by many light source images formed at a position P_2 is substantially round-shaped. Therefore, by simultaneously orthogonally projecting a projective relationship of the condenser optical system 3 and forming an outer shape (contour) of the secondary light source, spatial coherency within the illumination region IF formed on the mask 5 can be uniform regardless of the location and the direction.

[0034]

Furthermore, a shape of a reflecting surface of the respective reflecting elements within the reflecting element group 2 is constituted so that the projective relationship becomes the same as the condenser optical system 3, so distortion aberration cannot be generated in the reflecting element group 2 and the condenser optical system 3, and illuminance in the arc-shaped illumination region formed on the reflecting type mask 5 can be further uniform.

Thus, an example was described in which the condenser mirror which structures the condenser optical system 3 and the respective reflecting elements E which structure the reflecting element group 2 are eccentric spherical reflecting surfaces, but they also can be aspherical.

[0035]

Here, specific numerical values are listed for the condenser optical system 3 and the reflecting element group 2 within the exposure apparatus shown in Fig. 1. The following numerical value example shows a case when the condenser mirror which structures the respective reflecting elements E and the condenser optical system 3 which structures the reflecting element group 2 are aspherical.

As shown in Fig. 4, an arc curvature R_{IF} of the arc-shaped illumination region IF formed on the reflecting mask 5 is 96 mm, angle α_{IF} of the arc-shaped illumination region IF is 60°, a length L_{IF} between both ends of the arc-shaped illumination region IF is 96 mm, an arc width t_{IF} of the illumination region IF is 6 mm, an illumination numerical aperture NA on the

reflecting mask 5 is 0.015, inclination of a main light beam of illumination light with respect to a normal line of the reflecting mask 5 is 30 mrad (in other words, the entrance pupil position of the projection system 6 is 3119 mm from the reflecting mask 5), and a light beam diameter ϕ supplied from the laser light source is approximately 42 mm.

[0036]

Furthermore, as shown in Fig. 6(a), a reflecting curved surface (aspherical) of the reflecting element E within the reflecting element group 2 is AS_E, a reference spherical surface in a vertex O_E of the reflecting curved surface of the reflecting element E is S_E, a center of curvature of the reference spherical surface is O_{RE}, and an XY coordinate system is considered in which a direction passing through the vertex O_E of the reflecting curved surface of the reflecting element E and perpendicular to a contact plane in the vertex O_E of the reflecting curved surface of the reflecting element E is an X axis (the optical axis Ax_E of the reflecting element E is an X axis), a direction passing through the vertex O_E of the reflecting curved surface of the reflecting element E and parallel to a contact plane in the vertex O_E of the reflecting curved surface of the reflecting element E is the Y axis, and the vertex O_E of the reflecting curved surface of the reflecting element E in which the X and Y axes are intersected is the origin.

[0037]

Here, Fig. 6(a) shows a cross-sectional view of the reflecting curved surface of the reflecting element E within the reflecting element group 2. Fig. 6(b) shows a front view of the reflecting element E in the reflecting element group 2.

When a distance along a direction of an X axis (optical axis Ax_E) up to the reflecting surface (aspherical) of the reflecting element E from the contact plane in the vertex O_E of the reflecting curved surface of the reflecting element E is x, a distance along a direction of a Y axis up to the reflecting surface (aspherical) of the reflecting element E from the X axis (optical axis Ax_E) is y, a radius of curvature (reference radius of curvature of the reflecting element E) of the reference spherical surface S_E going through the vertex O_E of the reflecting curved surface of the reflecting element E is R_E, and aspherical coefficients C_2, C_4, C_6, C_8, and C_{10}, a reflecting surface of the respective reflecting elements E which structure the reflecting element group 2 is constituted by an aspherical surface which can be expressed by the following aspherical surface equation.

$$x(y) = (y^2 / R_E) / [1 + (1 - y^2 / R_E^2)^{0.5}]$$

$$+ C_2 y^2 + C_4 y^4 + C_6 y^6 + C_8 y^8 + C_{10} y^{10}$$

$R_E = -\ 183.3211$

$C_2 = -\ 5.37852 \times 10^{-4}$

$C_4 = -\ 4.67282 \times 10^{-8}$

$C_6 = -\ 2.11339 \times 10^{-10}$

$C_8 = \ 5.71431 \times 10^{-12}$

$C_{10} = -\ 5.18051 \times 10^{-14}$

As shown in Fig. 6(a), the respective reflecting elements E which structure the reflecting element group 2 have a reflecting cross-sectional shape sandwiched by height y_1 from the optical axis Ax_E and height y_2 from the optical axis Ax_E in a mirror cross-sectional direction. In a front direction as shown in Fig. 6(b), an arc-shaped aspherical eccentric mirror is constituted in which arc open angle α_E is 60°, and the length between both arc ends is 5.25 mm. Furthermore, height y_1 from the optical axis Ax_E is 5.085 mm, and height y_2 from the optical axis Ax_E is 5.415 mm.

[0038]

In this case, the light source image I formed by the reflecting element E is positioned and distant from the vertex O_E of the reflecting curved surface of the reflecting element E by only 76.56 mm ($=x_I$) in a direction of the optical axis Ax_E of the reflecting element E. In a direction perpendicular to the optical axis Ax_E of the reflecting element E, the light source image I is positioned on the optical axis Ax_E distant from the arc center diameter of the reflecting element E by 5.25 mm. Furthermore, the position of the light source image I in a direction perpendicular to the optical axis Ax_E of the reflecting element E is positioned on the optical axis Ax_E distant from the arc outer diameter of the reflecting element E by 5.085 mm ($=y_1$) and positioned on the optical axis Ax_E distant from the arc outer diameter of the reflecting element E by 5.415 mm ($=y_2$).

[0039]

Furthermore, as shown in Fig. 2, by arranging many eccentric aspherical type reflecting elements E having the above-mentioned dimension, a desired reflecting element group 2 can be structured.

The following shows a specific numerical value example of the condenser mirror 3 as a condenser optical system in the case of using the reflecting elements E having many eccentric aspherical surfaces with the above-mentioned dimension.

[0040]

As shown in Fig. 7, the reflecting curved surface (aspherical surface) of the condenser mirror 3 is AS_C, a reference spherical surface in the vertex O_C of the reflecting curved surface of the condenser mirror 3 is S_C, a center of curvature of a reference spherical surface is O_{RC}, an XY coordinate system is considered in which a direction passing through the vertex O_C of the reflecting curved surface of the condenser mirror 3 and perpendicular to the contact plane in the vertex O_C of the reflecting curved surface of the condenser mirror 3 is an X axis (the optical axis Ax_C of the condenser mirror 3 is an X axis), a direction passing through the vertex O_C of the reflecting curved surface of the condenser mirror 3 and parallel to a contact plane in the vertex O_C of the reflecting curved surface of the condenser mirror 3 is a Y axis, and the vertex O_C of the reflecting curved surface of the condenser mirror 3 in which the X axis and the Y axis are intersected is an origin.

[0041]

Here, Fig. 7 shows a cross-sectional view of the reflecting curved surface of the condenser mirror 3.

When a distance along a direction of an X axis (optical axis Ax_C) up to the reflecting surface (aspherical surface) of the condenser mirror 3 from the contact plane in the vertex O_C of the reflecting curved surface of the condenser mirror 3 is x, a distance along a direction of a Y axis up to the reflecting surface (aspherical surface) of the condenser mirror 3 from the X axis (optical axis Ax_C) is y, a radius of curvature (a reference radius of curvature of the condenser mirror 3) of a reference spherical surface going through the vertex O_C of the reflecting curved surface of the condenser mirror 3 is R_C, and aspherical coefficients are C_2, C_4, C_6, C_8, and C_{10}, the reflecting surface of the condenser mirror 3 is constituted by an aspherical surface which can be expressed by the following aspherical equation.

$$X(y) = (y^2 / R_c) / [1 + (1 - y^2 / R_E^2)^{0.5}]$$
$$+ C_2 y^2 + C_4 y^4 + C_6 y^6 + C_8 y^8 + C_{10} y^{10}$$

$R_C = -3518.74523$

$C_2 = -3.64753 \times 10^{-5}$

$C_4 = -1.71519 \times 10^{-11}$

$C_6 = 1.03873 \times 10^{-15}$

$C_8 = -3.84891 \times 10^{-20}$

$C_{10} = 5.12369 \times 10^{-25}$

However, the light source image I formed by the reflecting element group 2 is formed in the surface P_2 perpendicular to the optical axis Ax_c of the condenser mirror 3, the surface P_2 in which this light source image I is formed is removed by 2009.8 mm (x_{IC}) along the optical axis Ax_c from the vertex O_c of the reflecting curved surface of the condenser mirror 3.

[0042]

An arc-shaped irradiating region IF in which an illumination distribution and spatial coherency are uniform is formed by an eccentric aspherical type condenser mirror 3 and the reflecting element group 2 which is constituted by many reflecting elements E having an eccentric aspherical type reflecting surface shown by the above-mentioned numerical value example. At this time, as shown in Fig. 7, the center C_{IF} in the width direction of the arc-shaped irradiating region IF formed by the condenser mirror 3 is separated by 1400 mm ($=x_M$) from the vertex O_C of the reflecting curved surface of the condenser mirror 3, and in the height direction of the optical axis Ax_C of the condenser mirror 3, it is located at a position of 96 ($=y_{MC}$) from the optical axis Ax_C.

[0043]

According to the above-mentioned structure, an illumination region IF can be formed in which illumination and spatial coherency are uniform on the reflecting type mask 5.

Furthermore, when the focal length of the respective optical elements E which structure the optical element group 2 is f_F and the focal length of the condenser optical system 3 is f_C, it is preferable that the relationship of the following condition (2) can be satisfied.

(2) $\quad 0.01 < | f_F/f_C | < 0.5$

If the maximum of this condition (2) is exceeded, when the respective optical elements which structure the optical element group 2 have an appropriate power, the focal length of the condenser optical system becomes too short. Because of this, aberration is significantly generated in the condenser optical system, so it is difficult to form an arc-shaped uniform illumination region on the mask 5. On the other hand, if the minimum of condition (2) is not met, when the respective optical elements which structure the optical element group have an appropriate power, the focal length of the condenser optical system becomes too long, the

condenser optical system itself becomes too large, and it is difficult to structure a compact device.

[0044]

For example, a corresponding value of the above-mentioned condition (2) is listed in accordance with the numerical value example of the condenser mirror 3 and the respective optical elements E which structure the above-mentioned optical element group 2.

As mentioned earlier, a radius of curvature R_E of the respective optical elements which structure the optical element group 2 is -183.3211 mm, so the focal length f_F of the reference of the optical element E is 91.66055 mm ($f_F = -R_E / 2$). Additionally, the radius of curvature of the condenser mirror 3 is -3518.74523 mm, so the focal length f_C of the reference of the optical element E is 1759.3726 mm ($f_C = -R_C / 2$). Therefore, $| f_F/f_C | = 0.052$ is established, the relationship which is shown in the above-mentioned condition is satisfied, and while a desired illumination region is maintained, a compact device is structured.

[0045]

The following explains a second embodiment according to this invention with reference to Figs. 8, 9(a) and (b), 10(a) and (b), and 11(a) and (b).

In the above-mentioned first embodiment, an example is shown in which the multi-light source formation optical system (optical integrator) is constituted by one reflecting element group 2 only, but in the second embodiment, an example is shown in which the multi-light source formation optical system (optical integrator) is constituted by two reflecting element groups (20a, 20b).

[0046]

Fig. 8 is a diagram showing a schematic structure of a second embodiment according to this invention. Figs. 9(a) and (b) are front views showing structures of two reflecting element groups (20a, 20b) as a multi-light source formation optical system (optical integrator). Figs. 10(a) and (b) are diagrams showing the structures of the respective reflecting elements E_1 which structure the first reflecting element group 20a. Figs. 11(a) and (b) are diagrams showing the structures of the respective reflecting elements E2 which structure the second reflecting element group 20b. Fig. 12 is a diagram showing an operation of two reflecting element groups (20a, 20b) as a multi-light source formation optical system (optical integrator) shown in Fig. 8.

[0047]

As shown in Fig. 8, an X-ray radiation device 1 as a light source means is a laser plasma X-ray source which radiates X ray having a wavelength of 10 nm-15 nm, a synchrotron generation device which provides radiation light having a wavelength of 10 nm-15 nm, or the like. Radiation light (X-ray) provided from the X-ray radiation device 1 is radiated toward the multi-light source formation optical system (optical integrator) 2.

[0048]

Here, the multi-light source formation optical system (optical integrator) 2 is constituted by the first reflecting element group 20a and the second reflecting element group 20b.

First, the first reflecting element group 20a is explained. With respect to the first reflecting element group 20a, many first reflecting elements (optical elements) E_1 along a predetermined reference plane P_a perpendicular to a YZ plane are two-dimensionally arranged in a dense manner. Specifically, as shown in Fig. 9(a), the first reflecting element group 20a has many reflecting elements E_1 having a reflecting curved surface in which a contour (outer shape) is formed in an arc shape. Furthermore, there are five rows of the first reflecting element group 20a, in which many first reflecting elements are arranged along the Z direction, the rows arranged along the Y direction. Furthermore, five rows of the first reflecting elements are constituted so as to have a substantially round shape as a whole.

[0049]

Furthermore, the contour shape (arc shape) of the reflecting elements E is similar to the shape of the arc-shaped illumination region IF formed on the reflecting mask 5 as an illuminated surface which will be discussed later.

As shown in Figs. 10(a) and (b), the respective reflecting elements E_1 have a shape in which part of the reflecting curved surface of a predetermined radius of curvature R_{E1} is cut off in a predetermined region which is decentered from the optical axis Ax_{E1} so that the contour (outer shape) becomes an arc. The center C_{E1} of the arc-shaped reflecting elements E_1 is positioned at height h_E from the optical axis Ax_{E1}. Therefore, the reflecting surface which is decentered from the respective reflecting elements E_1 is constituted by an eccentric spherical surface mirror having a predetermined radius of curvature R_{E1} as shown in Fig. 10(b).

[0050]

Therefore, as shown in Fig. 10(b), radiation light (X-ray) L which is incident from a predetermined oblique direction with respect to the optical axis Ax_{E1} of the reflecting element

E_1 forms a light source image I as it is condensed to a surface P_{FO} (position distant from the optical axis Ax_{E1}) perpendicular to the focal point F_{E1} of the reflecting element E_1. Furthermore, the focal length f_{E1} of the reflecting element E_1 at this time is a distance between a vertex O_{E1} of the reflecting curved surface of the reflecting element E_1 and the focal point F_{E1} of the reflecting curved surface of the reflecting element E_1, and if this is a radius of curvature R_{E1} of the reflecting curved surface of the reflecting element E_1, the relationship of the following equation (3) is established.

(3) $f_{E1} = -R_{E1} / 2$

In Fig. 8, radiation light (X-ray) which is obliquely incident from a predetermined direction to the first reflecting element group 20a is divided into arc-shaped light beams in a manner of wavefront dividing by a reflecting operation (or act) of the many reflecting elements E_1, whereby many light source images corresponding to the number of the many reflecting elements E1 are formed at a position P_b (the position of the surface of the respective reflecting elements which structure the second reflecting element group 20b) shifted from the incident light beam. In other words, if radiation light L is incident from an oblique direction with respect to the respective optical axis Ax_{E1} of the many reflecting elements E_1 which structure the first reflecting element group 20a, the light source image I is respectively formed in the surface P_b passing through the focal point F_{E1} which exists on the respective optical axes Ax_E by the reflecting condensing operation of the respective reflecting elements E_1. Many secondary light sources are substantially formed in the plane P_b (P_{FO} of Fig. 10(b)) in which many light source images I are formed.

[0051]

In the plane P_b in which many light source images I are formed, as shown in Fig. 9(b), the second reflecting element group 20b is arranged.

Here, radiation light supplied from the radiation light source device 1 radiates a light beam having an angle of divergence in a certain range in addition to a parallel light beam. Because of this, in the plane P_b, a certain size of the light source images is formed by the first reflecting element group 20a. Therefore, this second reflecting element group 20b functions as a field mirror group in order to effectively use radiation light supplied from the radiation light source device 1. That is, many second reflecting elements E_2 which structure the second reflecting element group 20b function as a field mirror.

[0052]

The structure of the second reflecting element group 20b is explained. With respect to the second reflecting element group 20b, many second reflecting elements (optical elements) E_2 along a predetermined second reference plane (surface P_b in which many light source images I are formed) perpendicular to the YZ plane are two-dimensionally arranged in a dense manner. Specifically, as shown in Fig. 9(b), the second reflecting element group 20b has many reflecting elements E_2 having a reflecting curved surface in which a contour (outer shape) is formed in a rectangular shape. Furthermore, the second reflecting element group 20b has five rows arranged in the Y direction, of many second reflecting elements arranged along the Z direction. Furthermore, the five rows of the second reflecting elements are constituted so as to be a substantially round shape as a whole.

[0053]

That is, many second reflecting elements E_2 which structure the second reflecting element group 20b are respectively arranged opposite to the many first reflecting elements E_1 which structure the first reflecting element group 20a, in a one-to-one relationship.

Here, as shown in Figs. 11(a) and (b), the respective reflecting elements E_2 have a shape in which part of the reflecting curved surface of a predetermined radius of curvature R_{E2} is cut out in a predetermined region including the optical axis Ax_{E2} so that the contour (outer shape) becomes a rectangular shape. The center C_{E2} of the rectangular-shaped reflecting element E_2 matches the optical axis Ax_{E2} of this reflecting element E_2. Therefore, as shown in Figs. 11(a) and (b), the reflecting surface of the respective reflecting elements E_2 is constituted by a coaxial spherical mirror having a predetermined radius of curvature R_{E2}.

[0054]

Furthermore, a function as a light source image formation optical system in which many light source images I are formed, that is, a multi-light source formation optical system which forms many secondary light sources is obtained by two reflecting element groups of the first and second reflecting element groups.

A light beam from many light source images I reflected by the second reflecting element group 20a is incident to a condenser reflecting mirror 3 having an optical axis Ax_c as a condenser optical system. This condenser reflecting mirror 3 is constituted by one eccentric spherical surface mirror which is decentered with respect to the optical axis Ax_c. This eccentric spherical mirror has a predetermined radius of curvature R_c. The focal point of this condenser reflecting mirror 3 matches the secondary light source surface P2 in which many light source images I are formed by the second optical element group 20a. The center of

curvature O_c of the condenser reflecting mirror 3 exists at the center position (position in which the optical axis Ax_c and the surface P_2 in which the light source image I is formed are intersected) of many light source images I formed on the second reflecting element group or the center of the optical element group 2.

[0055]

Furthermore, the optical axis Ax_c of the condenser reflecting mirror 3 is parallel to the respective optical axes Ax_{E1} of the many optical elements E1 which structure the first optical element group 20a, but is not parallel to the respective optical axes Ax_{E2} of the many optical elements E2 which structure the second optical element group 20b. That is, the respective optical axes Ax_{E2} of the many optical elements E_2 which structure the second optical element group 20b is inclined by half the incident angle of the light beam as if the obliquely incident light beam were perpendicularly incident.

[0056]

After the respective light beams from many light source images I reflected by the second reflecting element group 20a are respectively reflectingly condensed by the condenser reflecting mirror 3, the reflecting type mask 5 as an illuminated surface is superimposingly illuminated in an arc shape via the flat mirror 4 as a deflecting mirror. Fig. 4 shows an arc-shaped illumination region IF formed on the reflecting type mask 5 when seen from a direction shown by arrow A of Fig. 8, that is, the rear surface of the reflecting type mask 5. The center of curvature O_{IF} of the arc-shaped illumination region IF exists on the optical axis Ax_p of the projection system shown in Fig. 1. Furthermore, if the flat mirror 4 of Fig. 8 is removed, the irradiating region IF is formed at a position of the irradiating surface IP of Fig. 8, and the center of curvature O_{IF} of the illumination region IF at this time exists on the optical axis Ax_C of the condenser optical system 3.

[0057]

Therefore, in the example shown in Fig. 8, the optical axis Ax_C of the condenser optical system 3 is not 90° deflected by the flat mirror 4, but if the optical axis Ax_C of the condenser optical system 3 is 90° deflected by an imaginary reflecting surface 4a of the flat mirror 4 shown in Fig. 8, the optical axis Ax_C of the condenser optical system 3 and the optical axis Axp of the projection system 6 are coaxial on the reflecting mask 5. Because of this, it can be said that these optical axes (Ax_C, Ax_P) are optically coaxial. Therefore, the condenser optical system 3 and the projection system 6 are arranged so that the respective

optical axes (Ax_C, Ax_P) optically pass through the center of curvature O_{IF} of the arc-shaped illumination region IF.

[0058]

Furthermore, in the surface of the reflecting type mask 5, a predetermined circuit pattern is formed, and this reflecting type mask 5 is held by a mask stage MS which can be two-dimensionally moved within the XY plane.

Light which has reflected from this reflecting type mask 5 is imaged onto the wafer 7 coated by resist as a photosensitive substrate via the projection system 6. Here, a pattern image of the arc-shaped reflecting mask 5 is projectingly transferred. The wafer 7 is held by a substrate stage WS which can be two-dimensionally moved within the XY plane.

[0059]

Here, the mask stage MS is two-dimensionally moved within the XY plane via the first driving system D_1, and the substrate stage WS is two-dimensionally moved within the XY plane via the second driving system D_2. In these two driving systems (D_1, D_2), the respective driving amounts are controlled by a control system 8.

Therefore, in the control system 8, by moving the mask stage MS and the substrate stage WS in directions opposite to each other (arrow direction) via the two driving systems (D_1, D_2), the entire pattern formed on the reflecting type mask 5 is scanningly exposed onto the wafer W via the projection system 6. By so doing, a desired circuit pattern in a photolithography process which fabricates a semiconductor device is transferred onto the wafer W, so a desired semiconductor device can be fabricated.

[0060]

As explained in the first embodiment, the projection system 6 having the optical axis Ax_p is constituted by an off-axis type reduction system having four aspherical surface mirrors (6a-6d) having an effective reflecting surface at a position separated from the optical axis Ax_C. The first, third, and fourth aspherical mirrors (6a, 6c, 6d) are constituted by concave surface type aspherical mirrors, and the second aspherical surface mirror 6b is constituted by a convex surface type aspherical mirror. The pupil of the projection system 6 exists on the reflecting surface of the third aspherical mirror 6c, and an aperture diaphragm or the like is arranged at the position P_S of this pupil.

[0061]

The following explains an operation of the first and second reflecting element groups (20a, 20b) of an example shown in Fig. 8 with reference to Fig. 12.

Fig. 12 is a diagram showing enlargement of a part of an illumination device which illuminates the reflecting mask 5 shown in Fig. 8. In order to clarify the explanation, Fig. 12 omits a flat mirror 4. Furthermore, the first reflecting element group 20a is constituted by two reflecting elements (E_{a1}, E_{b1}), and the second reflecting element group 20b is constituted by two reflecting elements (E_{a2}, E_{b2}).

[0062]

The first reflecting element group 20a includes two first reflecting elements (E_{a1}, E_{b1}) arranged along a predetermined first reference plane P_a, and the predetermined reference plane P_a is at a position which is optically conjugate to the reflecting mask 5 as an illuminated surface or in the vicinity of the conjugate position.

Additionally, the second reflecting element group 20b includes two first reflecting elements (Ea_2, Eb_2) arranged along a predetermined second reference plane P_b, and the predetermined reference plane P_b is at a position which is optically conjugate to the reflecting mask 6 as an illuminated surface or in the vicinity of the conjugate position.

[0063]

As shown in Fig. 12, radiation light (X ray), shown by solid lines, which is incident from a direction with respect to the reflecting element E_{a1} within the first reflecting element group 20a is divided into arc-shaped light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the reflecting element E_{a1}, and the wavefront-divided arc-shaped light beam (light beam shown by solid lines) forms a light source image I_1 at one end on the reflecting element E_{a2} within the second reflecting element group 20b by a condensing operation of the reflecting surface of the reflecting element E_{a1}.

[0064]

Furthermore, radiation light (X ray), shown by dotted lines, which is incident from a different direction to the reflecting element E_{a1} within the first reflecting element group 20a is divided into arc-shaped light beams in a manner of wavefront dividing so as to correspond to a contour shape of the reflecting surface of the reflecting element E_{a1}, and the wavefront-divided arc-shaped light beam (light beam shown by dotted lines) forms a light source image I_2 at the other end on the reflecting element E_{a2} within the second reflecting element group 20b by a condensing operation of the reflecting surface of the reflecting element E_{a1}.

[0065]

Therefore, when radiation light within an angle range, shown by dotted lines and solid lines, is incident to the reflecting element E_{a1} within the first reflecting element group 20a, a light source image which is connected between the light source image I_1 and the light source image I_2 is formed on the reflecting element E_{a2} within the second reflecting element group 20b.

After that, the light beam from the two light source images (I_1, I_2) is condensed by a reflecting condensing operation (field mirror operation) of the reflecting element E_{a2} within the second reflecting element group 20b and condensed by the reflecting condensing operation at the reflecting surface of the condenser optical system 3, and the reflecting type mask 5 is arc-illuminated in a superimposed manner from two directions. Additionally, the paper plane direction of Fig. 12 is a width direction of the arc-shaped illumination region formed on the reflecting type mask 5.

[0066]

Additionally, an optical operation (or action) by the reflecting element E_{b2} within the second reflecting element group 20b and the reflecting element E_{b1} within the first reflecting element group 20a is the same optical operation (or action) by the reflecting element E_{a1} within the second reflecting element group 20a and the reflecting element E_{a2} within the first reflecting element group 20b which were described above. Therefore, explanation is omitted here.

Thus, light from many light source images formed by the two reflecting element groups (20a, 20b) is superimposingly illuminated into an arc shape on the reflecting type mask 5, so that uniform illumination can be effectively accomplished. Furthermore, the light beam path from the light source image is effectively condensed by an operation (field mirror operation) of the respective reflecting elements E within the second reflecting element group 20b, so the size of the condenser optical system 3 can be made compact.

[0067]

Furthermore, as shown in Fig. 8, the light source image which is formed in the surface of the respective reflecting elements within the second reflecting element group 20b is re-imaged into a position P_S (entrance pupil of the projection system 6) of the pupil of the projection system 6, so that so-called Koehler illumination can be accomplished.

As shown in the second embodiment, for example, by using light with an angle of divergence and with a wavelength of 100 nm or less such as X ray, in order to expose a mask pattern onto the photosensitive substrate 7, even if the entire illumination device and

projection system are constituted by reflecting type members and reflecting type elements, by substantially maintaining Koehler illumination conditions, an arc-shaped illumination region in which illumination is uniform on the mask can be effectively formed.

[0068]

Furthermore, in the second embodiment, an example as a spherical-shaped reflecting surface is described in which a condenser mirror 3 which constitutes the condenser optical system and the respective reflecting elements (E_1, E_2) which structure the first and second reflecting element groups (20a, 20b) are both eccentric, but needless to say, these can also be aspherical.

Furthermore, in the second embodiment, an example is shown in which the condenser optical system 3 and the projection system 6 are arranged so that the optical axis Ax_C of the condenser optical system 3 is perpendicular to the optical axis Ax_P of the projection system 6. As shown in Fig. 13, by changing arrangement of the deflecting mirror (flat mirror), the condenser optical system 3 and the projection system 6 can also be arranged so that the optical axis Ax_C of the condenser optical system 3 and the optical axis Ax_P of the projection system 6 can be coaxial even in terms of their physical arrangement.

[0069]

Furthermore, the following explains modification of the second embodiment with reference to Figs. 14(a) and (b) and 15.

In this example, in order to further improve illumination effectiveness in the first and second reflecting element groups (20a, 20b) shown in Figs. 9(a) and (b), the first and second reflecting element groups (20a, 20b) shown in Fig. 8 can be constituted as shown in Figs. 14(a) and (b) and 15.

[0070]

First, the structure of the first reflecting element group 20a is explained. As shown in Fig. 14(a), the first reflecting element group 20a has, along the Y direction, three rows of many second reflecting elements, in which many first reflecting elements having an arc-shape contour (outer shape) are arranged along the Z direction.

The first reflecting element row G_{E11} is constituted by many reflecting elements (E_{11a}-E_{11v}). Furthermore, this first reflecting element row G_{E11} is arranged in a state in which arbitrary reflecting elements which constitute the first reflecting element row G_{E11} are rotated by a predetermined amount about an axis A_1 parallel to a Z axis crossing the center (center of the respective reflecting element) of the first reflecting element row.

[0071]

Furthermore, the second reflecting element row G_{E12} is constituted by many reflecting elements (E_{12a}-E_{12y}). Additionally, the second reflecting element row G_{E12} is arranged in a state in which arbitrary reflecting elements which structure the second reflecting element row G_{E12} are rotated by respective predetermined amounts about the axis A_2 parallel to the Z axis crossing the center (center of the respective reflecting elements) of the second reflecting element row.

[0072]

Furthermore, the third reflecting element row G_{E13} is constituted by many reflecting elements (E_{13a}-E_{13v}). Additionally, this third reflecting element row G_{E13} is arranged in a state in which arbitrary reflecting elements which structure the third reflecting element row G_{E13} are rotated by respective predetermined amounts about the axis A_3 parallel to the Z axis crossing the center (center of the respective reflecting elements) of the third reflecting element row.

[0073]

Next, the structure of the second reflecting element group 20a is explained. As shown in Fig. 14(b), the second reflecting element group 20b has nine rows, arranged along the Y direction, in which many second reflecting elements E2 having a substantially square-shaped contour (outer shape) are arranged along the Z direction.

Furthermore, the second reflecting element group 20b has a first part group G_{E21} which is constituted by first-third reflecting element rows, a second part group G_{E22} which is constituted by fourth-sixth reflecting element rows, and a third part group G_{E22} which is constituted by seventh-ninth reflecting element rows.

[0074]

Here, in the surface of the respective reflecting elements E_2 which structure the first part group G_{E21}, a light source image which is condensed by the respective reflecting elements (E_{11a}-E_{11v}) of the first reflecting element row G_{E11} within the first reflecting element group 20a is respectively formed.

Additionally, in the surface of the respective reflecting elements E_2 which structure the first part group G_{E22}, a light source image which is condensed by the respective reflecting elements (E_{12a}-E_{12v}) of the second reflecting element row G_{E12} within the first reflecting element group 20a is respectively formed.

[0075]

Furthermore, in the surface of the respective reflecting elements E_2 which structure the third part group G_{E23}, a light source image which is condensed by the respective reflecting elements (E_{13a}-E_{13v}) of the third reflecting element row G_{E13} within the first reflecting element group 20a is respectively formed.

Specifically, as shown in Fig. 15, the respective reflecting elements (E_{11a}-E_{11k}) which structure the first reflecting element row G_{E11} are arranged in a state in which arbitrary reflecting elements which structure the first reflecting element row G_{E11} are rotated by respective predetermined amounts about the axis A_1 parallel to the Z axis crossing the center (center C_{1a}-C_{1k} of the respective reflecting elements) of the center of the first reflecting element row. For example, the reflecting element E_{11a} is fixed and arranged in a state which is rotated counter clockwise about the axis A_1 by a predetermined amount (micro amount). This reflecting element E_{11a} forms arc-shaped light source image I_a of a certain size on the uppermost part of the third row of the reflecting element E_2 of the first part group G_{E21}.

[0076]

Furthermore, the reflecting element E_{11f} is fixed in a state which is rotated counter clockwise about the axis A_1 by a predetermined amount (micro amount). This reflecting element E_{11f} forms a round-shaped light source image I_f on the second reflecting element E_2 from the top of the first row of the first part group G_{E21}.

Additionally, the reflecting element E_{11K} is fixed without being rotated about the axis A_1, and the reflecting element E_{11k} forms a round-shaped light source image I_f on the fourth reflecting element E_2 from the top of the second row of the first part group G_{E21}. The optical axis of the reflecting element E_{11k} at this time is parallel to the optical axis of the reflecting elements which structure the first part group G_{E21}.

[0077]

This type of structure shown in Fig. 15 is the same between the second reflecting element row G_{E12} in the first reflecting element group 20a and the second part group G_{E22} and the third reflecting element row G_{E13} in the first reflecting element group 20a and the second part group G_{E23}.

Thus, according to the structure of the first and second reflecting elements (20a, 20b) shown in Figs. 14(a) and (b) and 15, compared to the structure of the first and second reflecting elements (20a, 20b) shown in Fig. 9(a) and (b), it is difficult to eclipse a light source image by the contour (outer shape) of the second reflecting element, so illumination effectiveness can be improved.

[0078]

According to the above-mentioned first and second embodiments, the reflecting elements (E, E_1) having an arc-shaped contour (outer shape) in the first reflecting element group which structure at least part of the multi-light source formation means is constituted by an eccentric mirror which is decentered with respect to the optical axes (Ax_E, Ax_{E1}) of the elements, so it is acceptable to perform aberration correction in only the arc region in an image height (height from the optical axis). Therefore, restrictions on the optical design can be significantly relaxed compared to the case in which a non-eccentric reflecting element is designed. By so doing, aberration can be sufficiently controlled which is generated in the reflecting element of the first reflecting element group. Therefore, in an irradiating surface of the mask 5 or the like, there is an advantage that extremely desired uniform arc-shaped illumination can be accomplished.

[0079]

Furthermore, as the condenser optical system is also constituted by an eccentric mirror system, aberration which is generated in the condenser optical system can be sufficiently controlled. Therefore, the above-mentioned advantage can be additionally obtained. Furthermore, a condenser optical system can be constituted by one eccentric mirror, but can also be constituted by a plurality of eccentric mirrors.

In addition, if the first and second reflecting element groups are independently or integrally moved by only a micro amount in a predetermined direction (an optical axis of the reflecting element or the direction perpendicular to the optical axis) or at least one of the first and second reflecting element groups is inclined by only a micro amount, an illumination distribution or the like in an arc-shaped illumination region which is formed on an illuminated surface can be adjusted. Furthermore, at least one eccentric mirror which structures a condenser optical system can also be moved or inclined in a predetermined direction (an optical axis of the condenser optical system or the direction perpendicular to the optical axis) by only the micro amount.

[0080]

Furthermore, in order to structure a compact device in which a desired illumination region is maintained, needless to say, it is preferable that the first reflecting element group 20a and the condenser optical system 3 in the second embodiment satisfy the relationship of the above-mentioned condition (2).

In addition, in the above-mentioned respective embodiments, an example is shown in which the first and second optical elements which structure the multi-light source formation optical system are respectively constituted by reflecting mirrors, but they can also be constituted by a refractive lens elements. In this case, needless to say, it is preferable that a cross-sectional shape of the lens elements which structure the first optical element is arcuate.

[0081]

[Effects of the Invention]

As described above, according to this invention, by maintaining a numerical aperture of illumination light to be substantially constant, an illuminated surface can be uniformly effectively illuminated in an arc shape.

[Brief Description of the Drawings]

Fig. 1 is a schematic structural view of an exposure apparatus related to a first embodiment according to this invention.

Fig. 2 is a front view showing a structure of a reflecting element group 2 shown in Fig. 1.

Fig. 3(a) is a front view showing each reflecting element in the reflecting element group 2 shown in Fig. 2. Fig. 3(b) is a cross-sectional view showing a cross-sectional state of the reflecting element shown in Fig. 3(b).

Fig. 4 is a diagram showing an arc-shaped illumination region IF formed on a reflecting type mask 5.

Fig. 5 is a diagram showing an operation of the reflecting element group 2 shown in Fig. 1.

Fig. 6(a) is a cross-sectional view showing a cross-sectional shape of a reflecting element when each reflecting element in the reflecting element group 2 is aspherical. Fig. 6(b) is a front view of the reflecting element shown in Fig. 6(a).

Fig. 7 is a cross-sectional view showing a cross-sectional shape of a condenser mirror when the condenser mirror is aspherical.

Fig. 8 is a view showing a schematic structure of an exposure apparatus related to a second embodiment according to this invention.

Fig. 9(a) is a front view showing a structure of a first reflecting group 20a. Fig. 9(b) is a front view showing a structure of a second reflecting element group 20b.

Fig. 10(a) is a front view showing each reflecting element in the first reflecting element group 20a shown in Fig. 9(a). Fig. 10(b) is a cross-sectional view showing a cross section of the reflecting element shown in Fig. 10(a).

Fig. 11(a) is a front view showing each reflecting element in the second reflecting element group 20b shown in Fig. 9(b). Fig. 11(b) is a cross-sectional view showing a cross section of the reflecting element shown in Fig. 11(a).

Fig. 12 is a diagram showing an operation (or action) of the first and second reflecting element groups shown in Fig. 8.

Fig. 13 is a diagram showing a modified example of an exposure apparatus related to a second embodiment shown in Fig. 8.

Fig. 14(a) is a front view showing a modified example of the first reflecting element group 20a shown in Fig. 9(a). Fig. 14(b) is a front view showing a modified example of the second reflecting element group 20b of Fig. 9(b).

Fig. 15 is a diagram showing an operation (or action) of the first and second reflecting element groups (20a, 20b) shown in Fig. 14.

Figs. 16(a), (b), and (c) are diagrams showing a structure of a conventional illumination device.

[Explanation of the Symbols]

1 Light source device

2, 20a, 20b Reflecting element groups

3 Condenser optical system

4 Deflecting mirror

5 Reflecting type mask

6 Projection system

7 Wafer

[Document] Abstract

[Abstract]

[Object]

To provide an illumination device, having illumination effectiveness much better than a conventional device, which can provide high throughput as well, an exposure apparatus, and a method of fabricating a semiconductor device using the exposure apparatus.

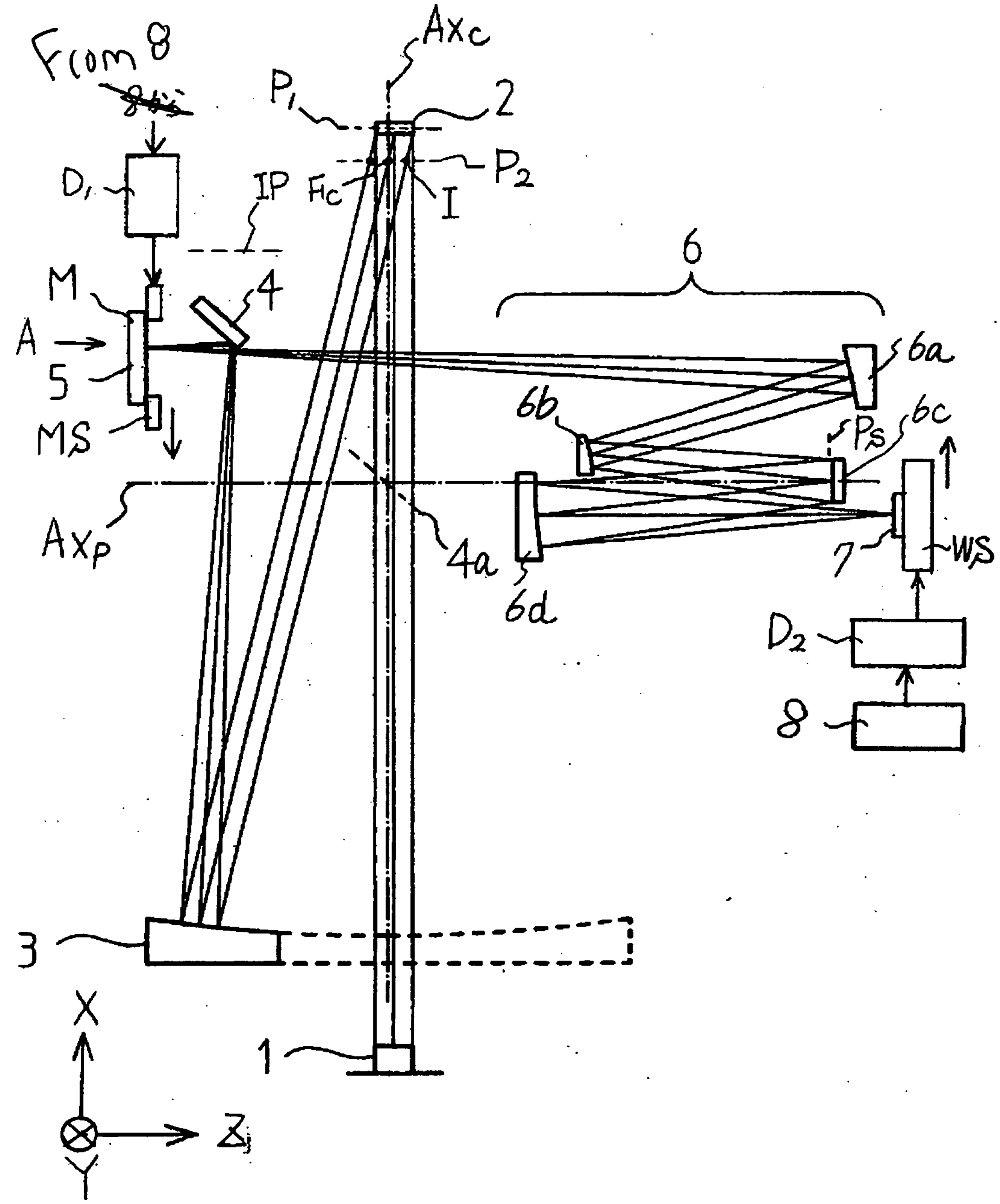
[Structure]

This invention is constituted by a light source means which provides a light beam, a multi-light source formation optical system which forms many light sources based on a light beam from the light source means, and a condenser optical system which illuminates an illuminated surface by converging light beams from the many light sources formed by the multi-light source formation optical system. The multi-light source formation optical system has a first optical element group including many first optical elements, and the many first optical elements respectively have a first optical surface having an arc-shaped contour in order to form many light sources by dividing a wavefront of the light beams from the light source means into many arc-shaped light beams.

[Selected Figure] Fig. 1

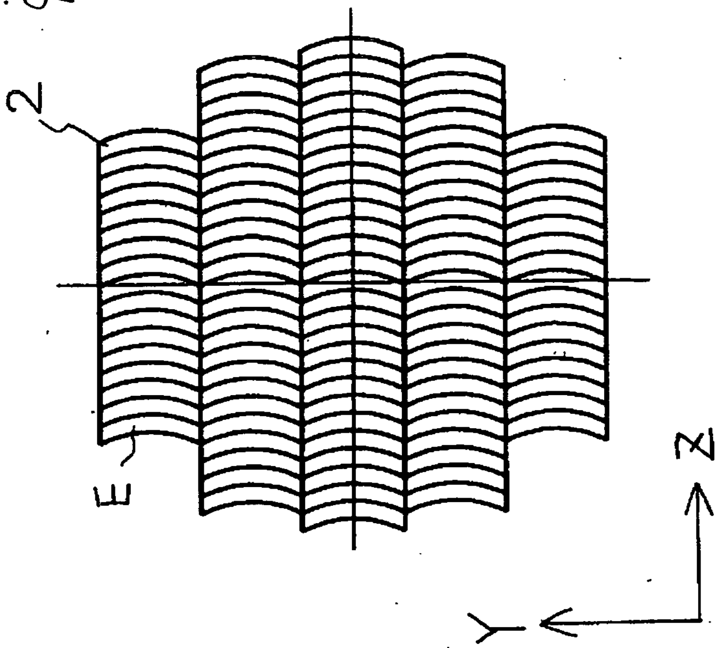
【書類名】　図面

~~【図1】~~ Fig. 1



~~【図2】~~

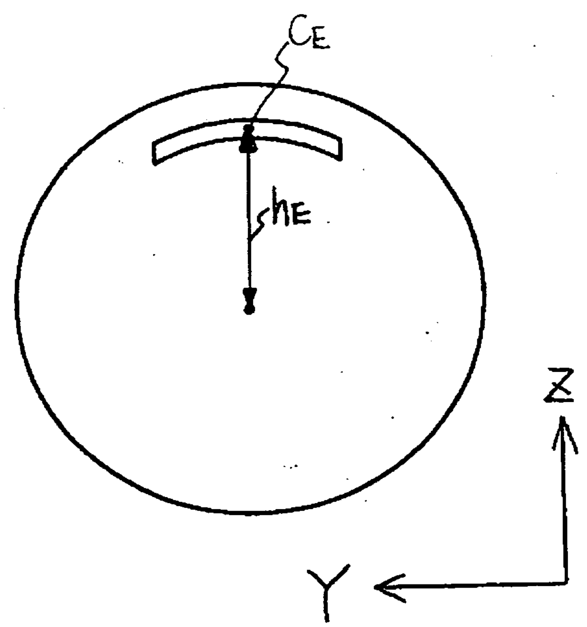
Fig.2



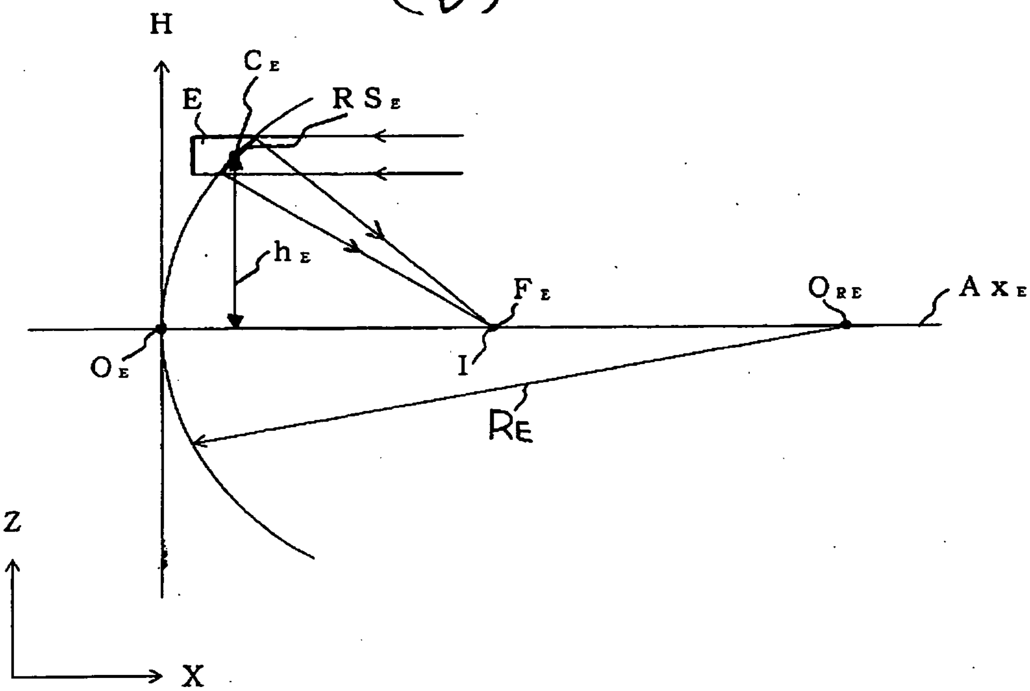
~~【図3】~~

Fig. 3

(a)

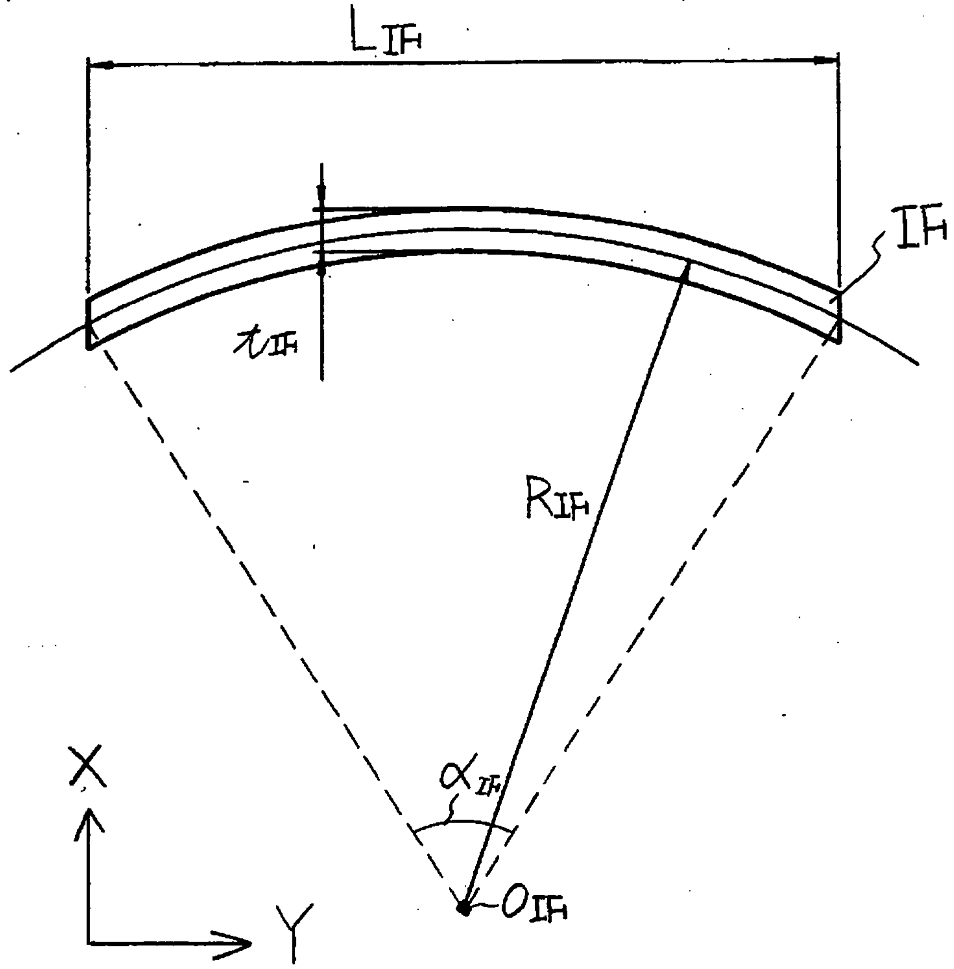


(b)



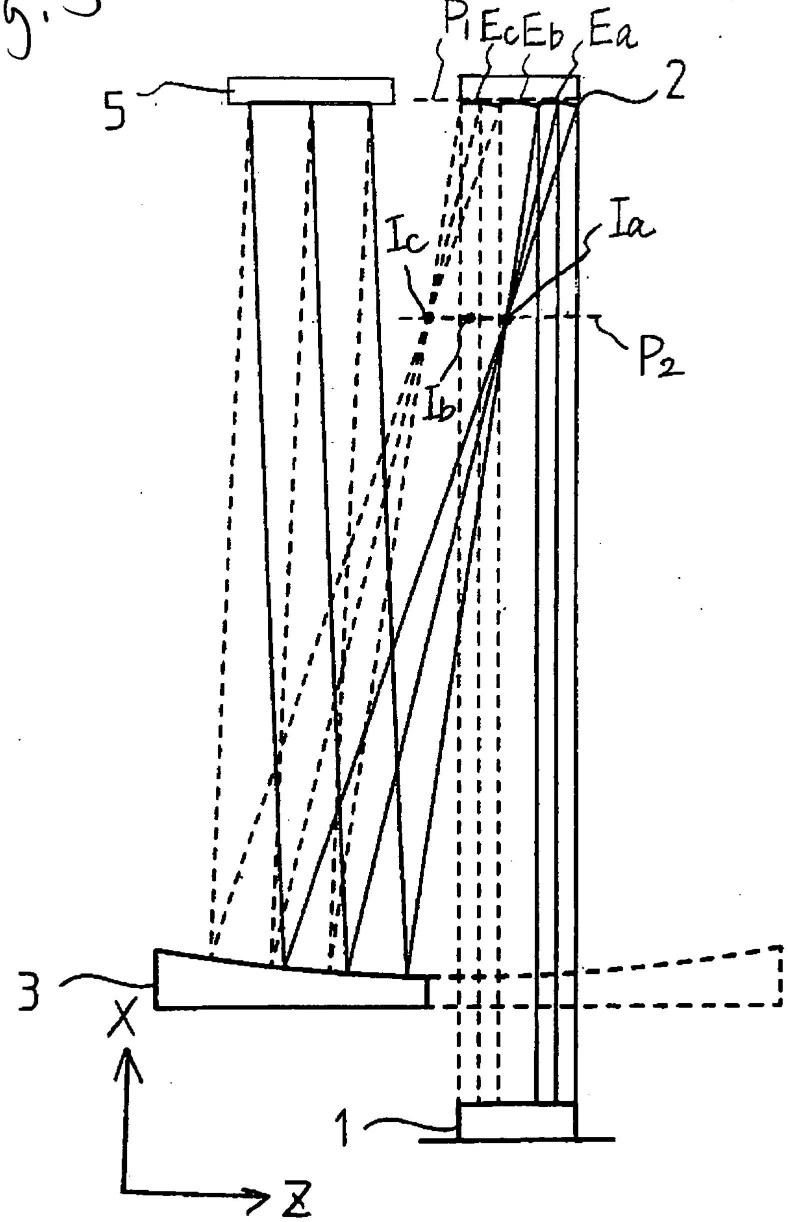
~~【図4】~~

Fig.4



【図5】

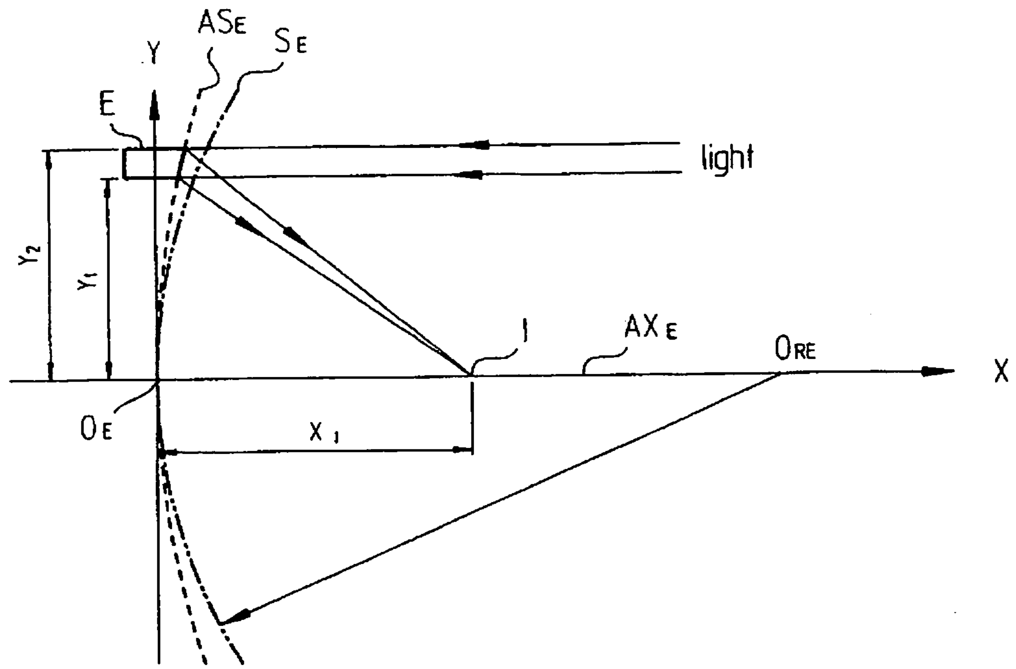
Fig.5



~~【図6】~~

Fig. 6

(a)



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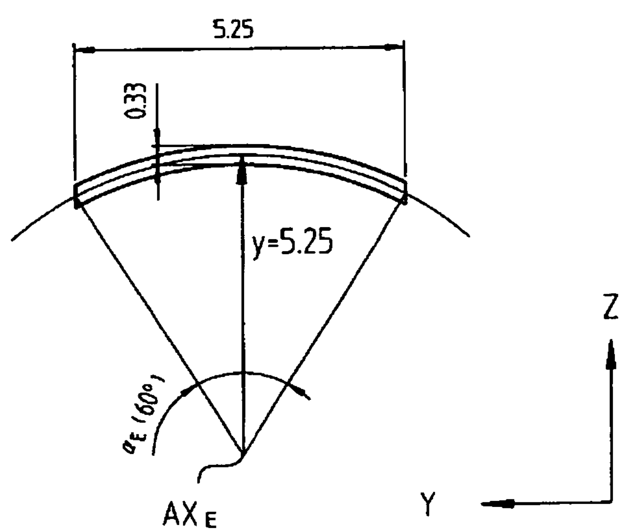
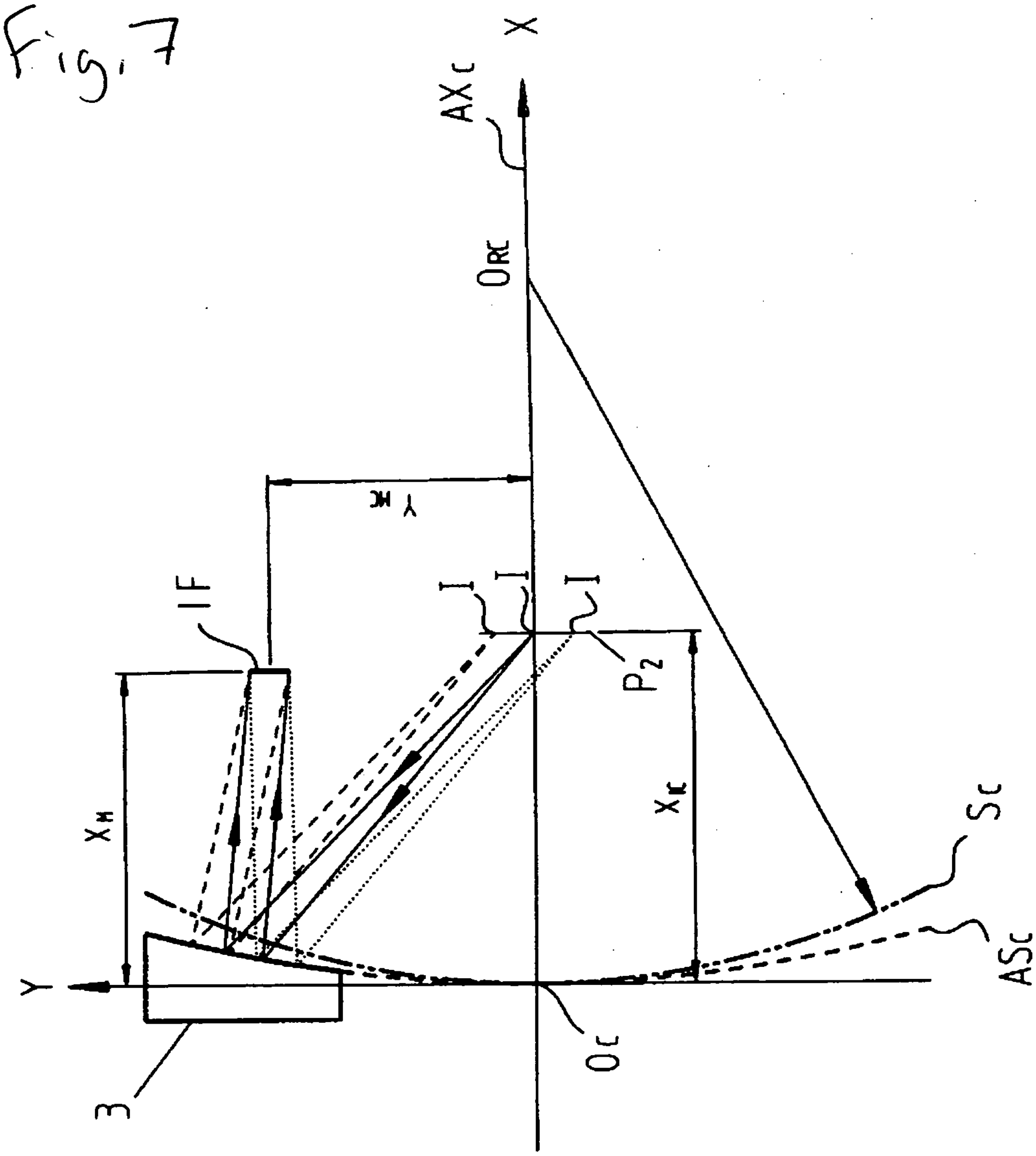


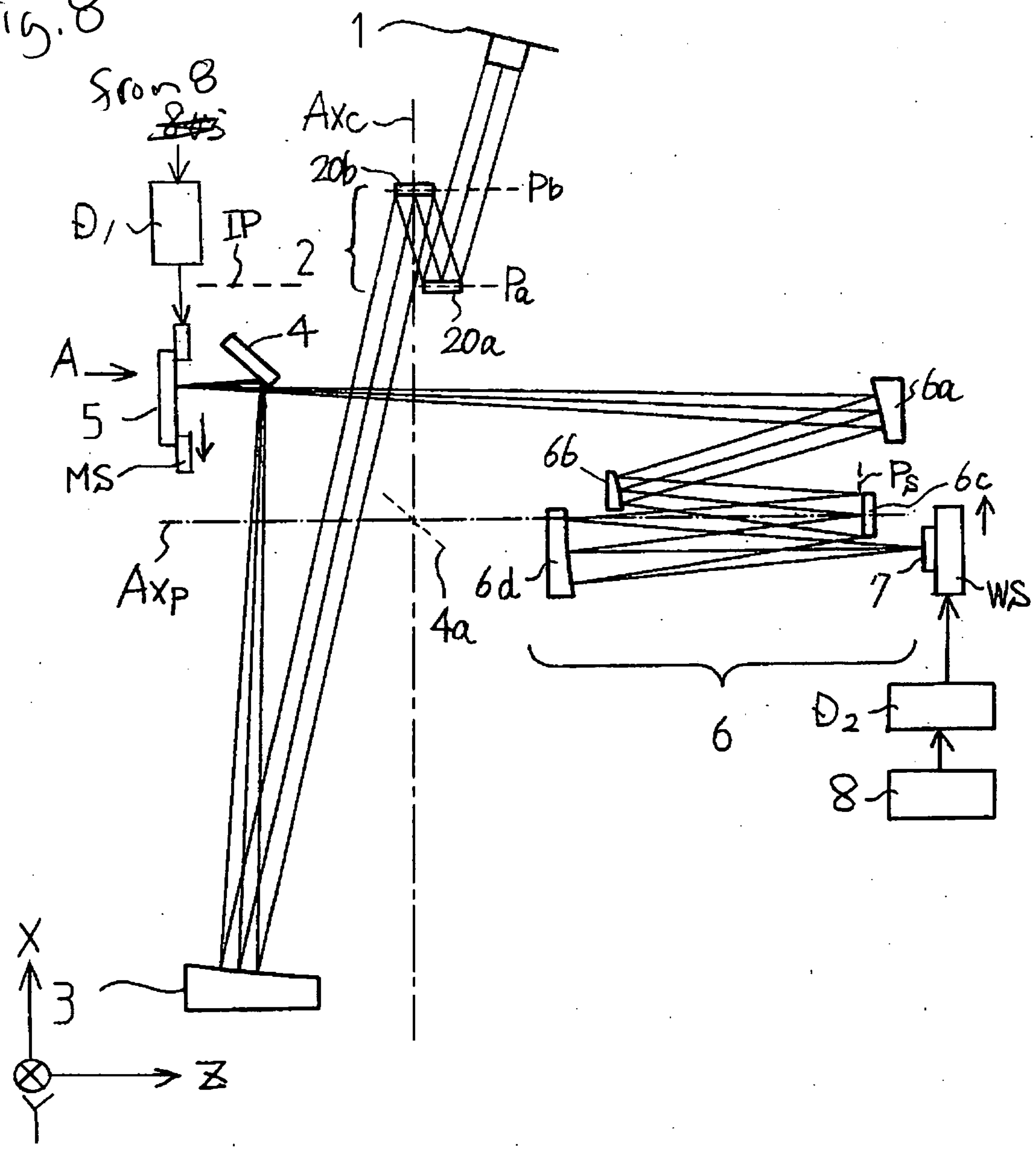
~~【~~図７】

Fig. 7



~~【図８】~~

Fig.8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IP
2
Axc
20b
Pb
Pa
20a
1
A
4
5
MS
6a
6b
Ps
6c
Axp
6d
4a
7
WS
6
D2
8
X
3
Z
Y

~~【図９】~~

Fig. 9

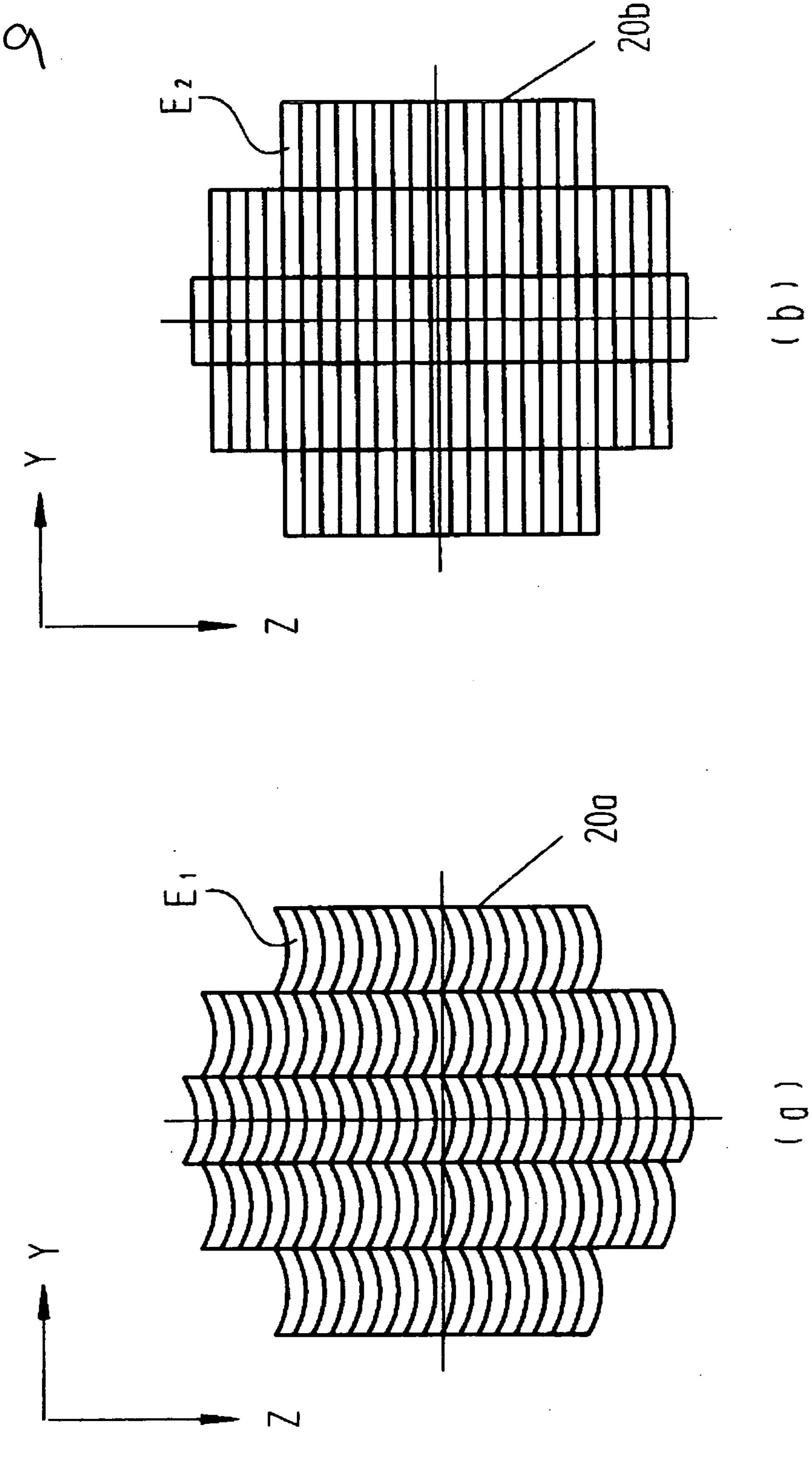
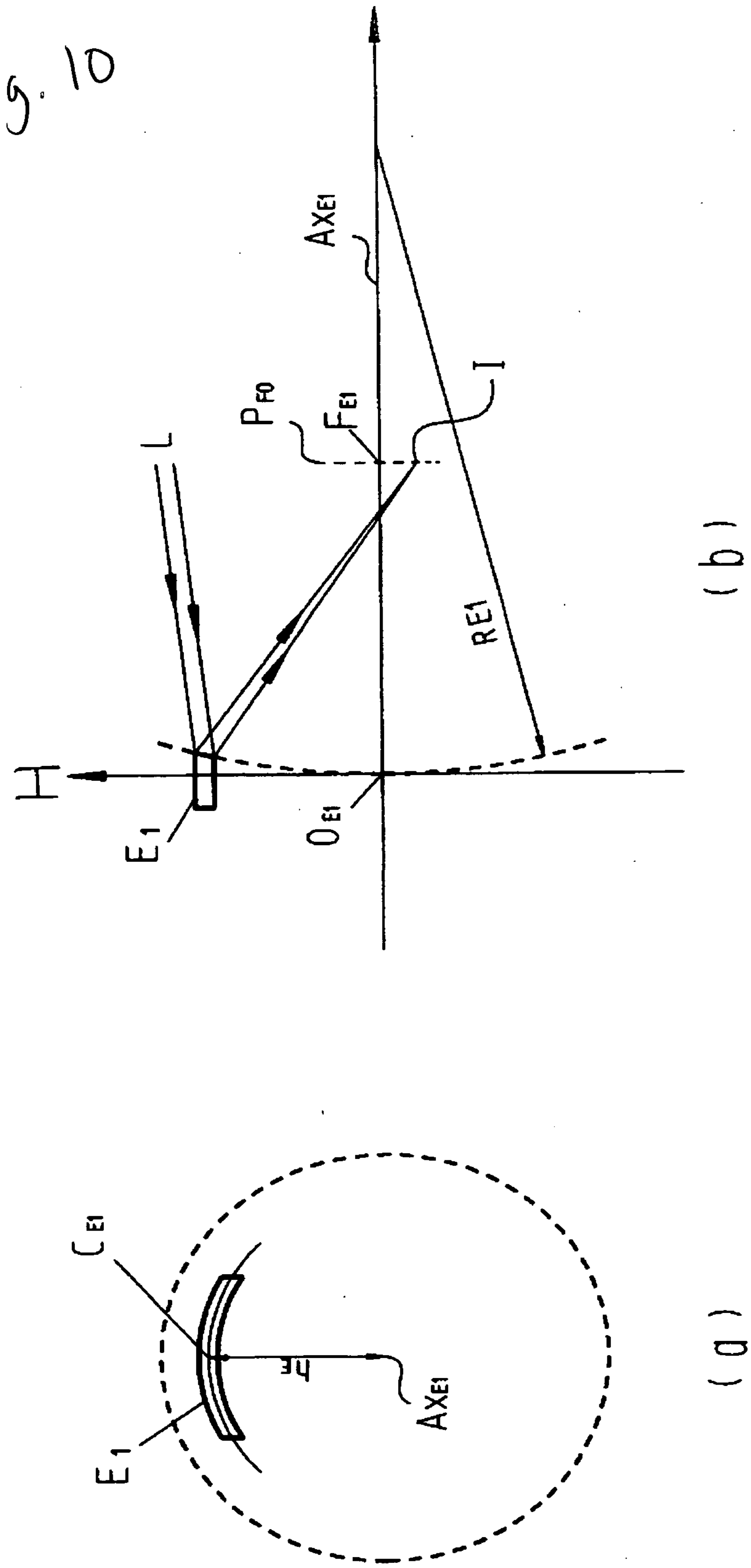
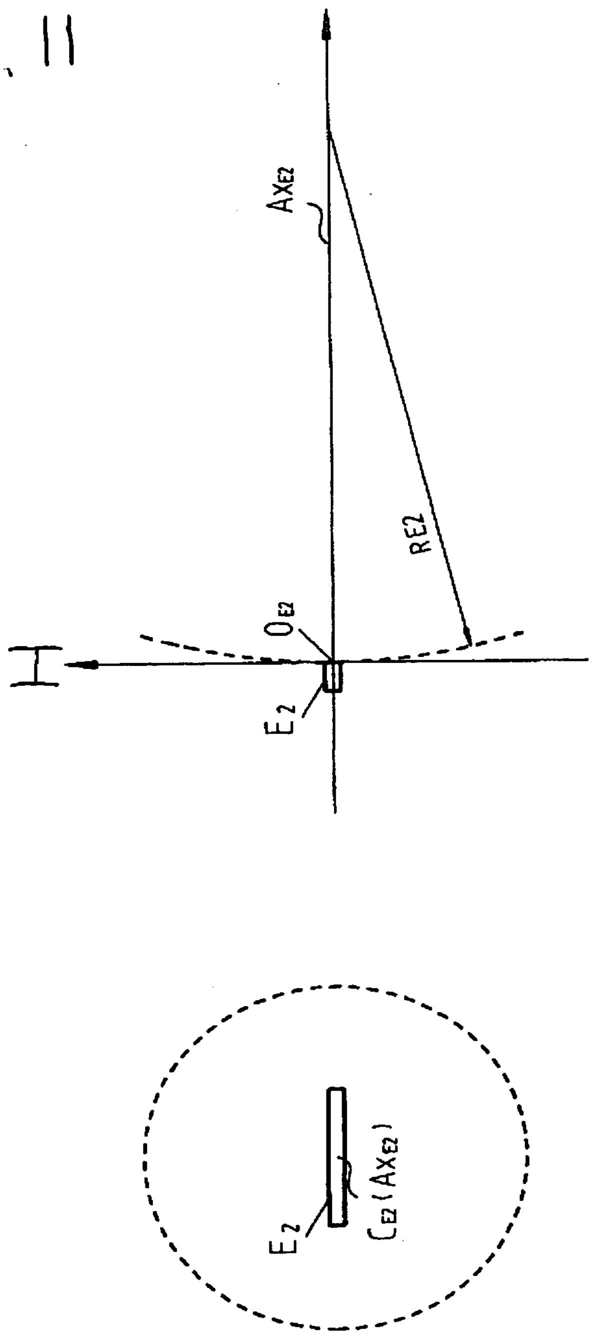


Fig. 10



~~【図１１】~~

Fig. 11

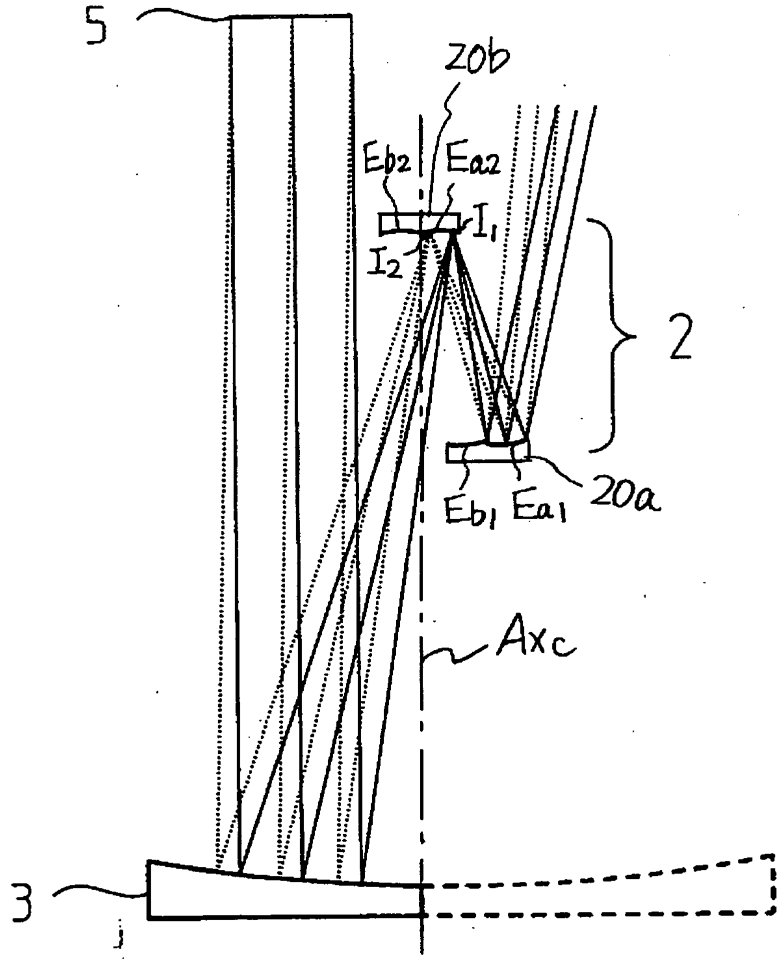


(b)

(a)

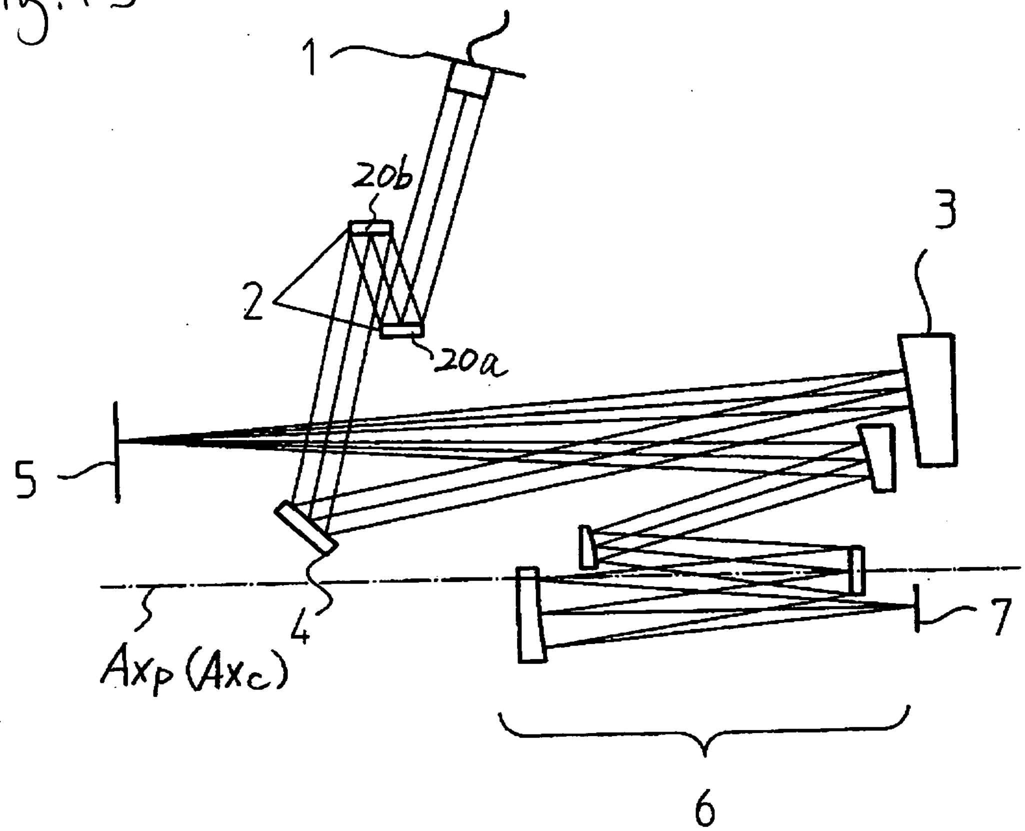
~~【図12】~~

Fig. 12



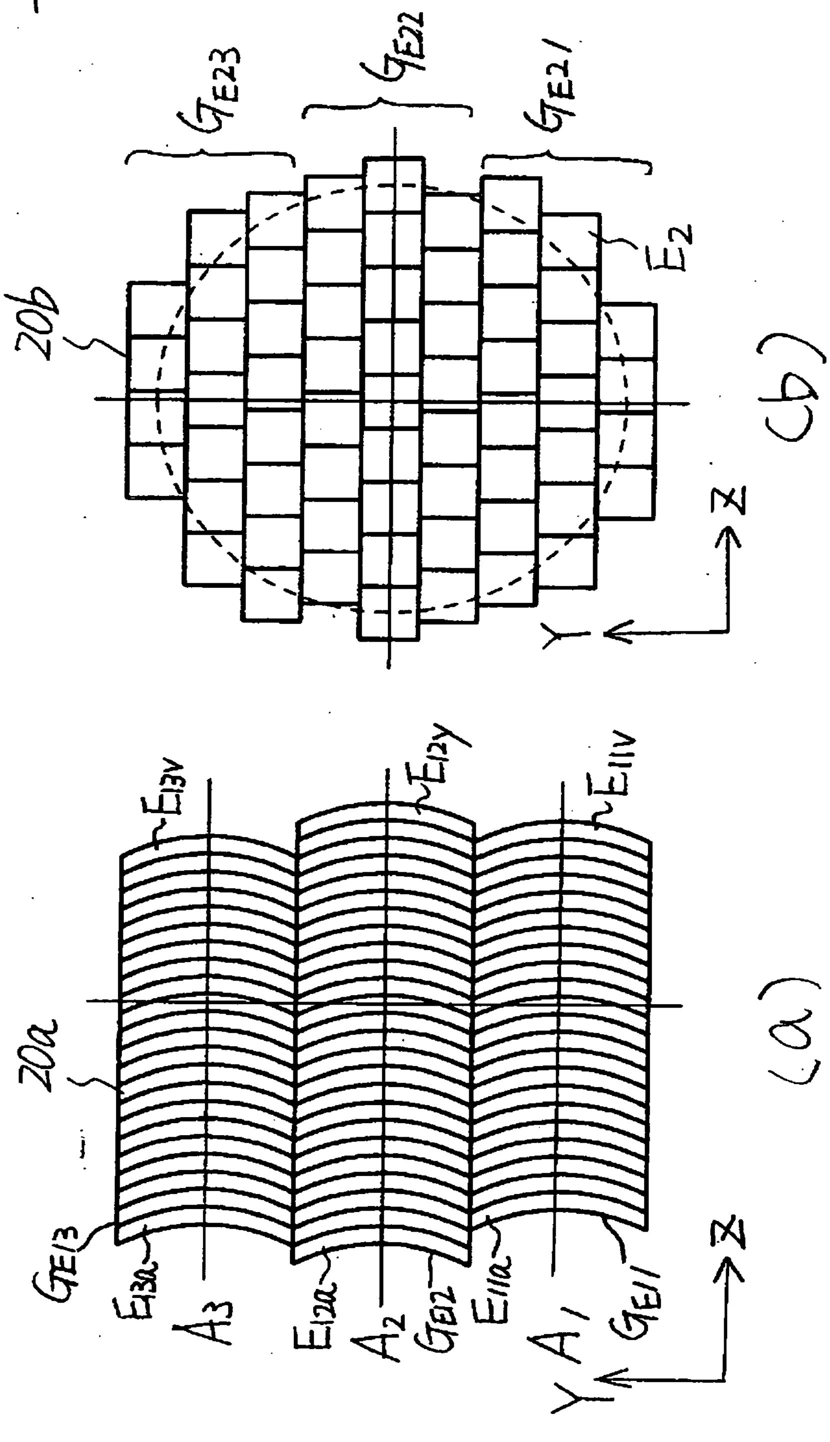
~~【図１３】~~

Fig.13



~~【図１４】~~

Fig. 14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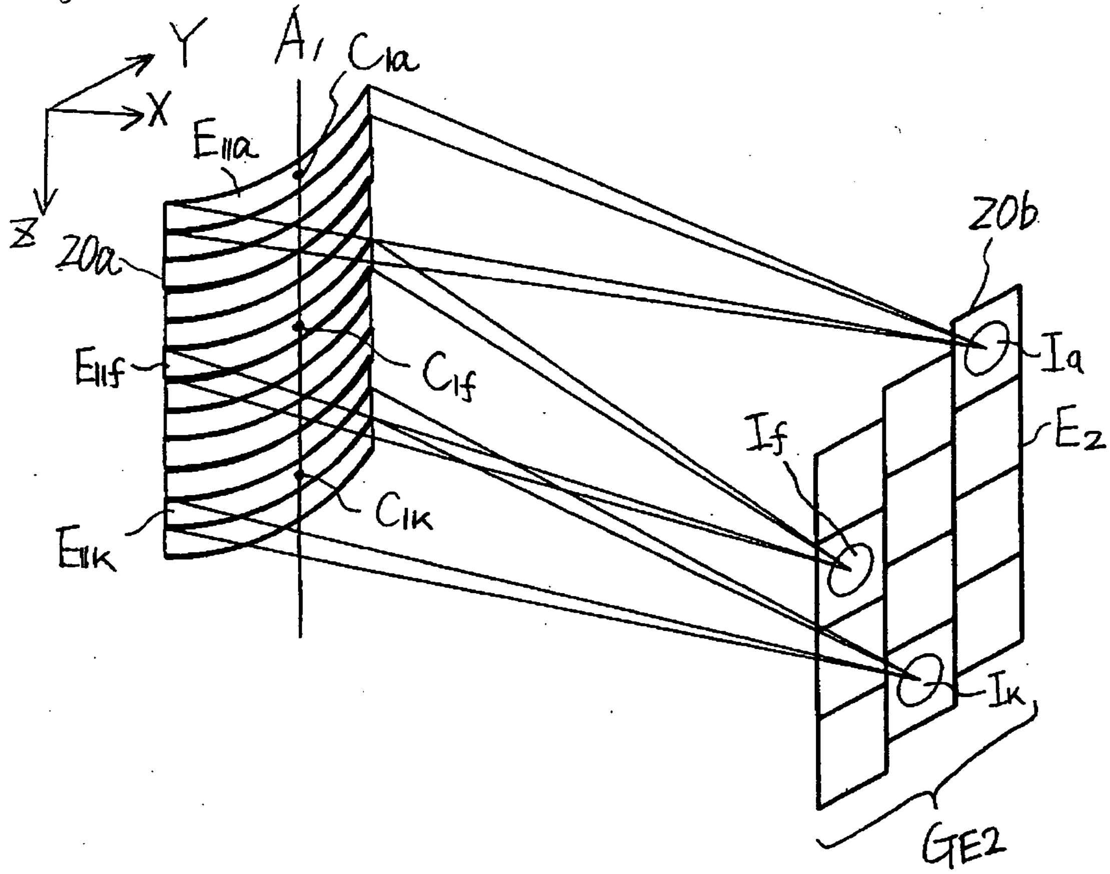
GE22
GE21
E2
20b
(b)
Z
Y
E13V
E12V
E11V
20a
(a)
GE13
E13a
A3
E12a
A2
GE12
E11a
A1
GE11
Z
Y

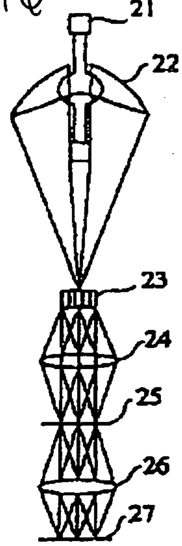
~~【図15】~~

Fig. 15

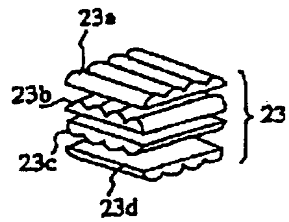


~~【図１６】~~

Fig.16



(a)



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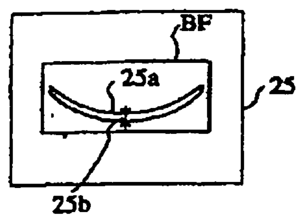

(c)